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Patents, Production and Tax Incentives

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March 1984



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Acknowledgements

This study has been commissioned by the Federal Department of Consumer and Corporate Affairs (CCA). The initial impetus and encouragement came from Russell Robinson. Lee McCabe was instrumental in organizing the study and the data collection. Guy Roberge helped in the provision of the patent information, through PATDAT. Humphrey Stead of Statistics Canada allowed us access to the detailed R&D data needed in the study. John McVey of Statistics Canada provided the help in obtaining the various financial statistics and in merging the various data files. The manuscript was typed by Norma Rankin, who brought her usual skill and patience to this task. Finally, I would like to thank Graham Corke whose efforts in organizing and gathering together the databank could only be described as superlative.

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1. INTRODUCTION

One of the most pressing issues confronting policy-makers, managers and economists centres around the reasons for the source of productivity decline in the Canadian economy. Numerous hypotheses have been advanced for the poor productivity performance. They range from oil price increases, excessive government regulation, sluggish product demand and low rates of research and development investment. Although each of these elements, to various degrees, may exert an influence on productivity growth, one of the major causes has been attributed to the rate of growth of the stock of research and development (R&D) capital.

What determines the rate of growth of R&D capital by a firm? The amount of resources devoted to R&D investment depends, quite naturally, on the profitability of its use. Accepting this proposition implies that the same elements which determine investment and factor demands influence R&D investment.

First, there are the product-induced benefits which affect the accumulation of R&D capital. If a change in technology reduces the cost of production then the return on R&D investment rises causing the stock of R&D or knowledge capital to expand. Second, technological change may alter the characteristics of the products sold by a firm. For example, a product may become more durable which, in turn, could cause the demand for the product to increase. Third, rising factor prices of labour, plant and equipment (P&E), materials, energy and other inputs will increase the profitability from undertaking R&D investment. The firm will substitute "know-how" for the use of the other factors of production.

The cost of undertaking R&D investment will affect the degree to which knowledge capital is expanded. The cost depends on the number of scientists and engineers, and the wage rates paid to these workers. In addition, the cost depends on the plant and equipment and other inputs used in the R&D capital accumulation process. To the extent that these costs increase, the expected return from R&D capital will decrease.

Besides being influenced by the quantity of resources a firm devotes to R&D investment, a firm's know-how can also be directly affected by other firms' knowledge producing behaviour. Technological change in any industry that supplies machinery, materials and other inputs may prompt R&D investment among its customers. For example, for approximately thirty years the processes by which aluminum was separated from its ore was the same due to the high cost of electrical power. However, technological change in electric power generation became a significant stimulus to technological change in the aluminum industry.

Another type of interdependence occurs among firms, as knowledge useful in the production of particular products turns out to be useful to others as well. Indeed, the U.S. space program undertaken by the National Aeronautics and Space Administration is filled with developments which have found their way into the hands of consumers. Thus knowledge may spill over from firm to firm even though they are not linked through any seller/purchaser arrangement.

The R&D investment of a firm is also affected by government policy. Indeed there are many distinct policies which influence knowledge accumulation. Legislation on patents, immigration

policy with respect to scientists and engineers, government grants, contracts and tax policy. In particular, tax policy is not solely restricted to R&D expenditures. Besides tax credits and allowances on R&D expenditures, the corporate tax rate, the treatment of depreciation on plant and equipment, as well as on R&D capital, and the tax rates on capital gains, royalties, interest and dividend income, influence R&D investment.

The importance of R&D investment in productivity growth, and in turn, output growth, have led many different groups in Canadian society to advocate that the government encourage this type of activity. In particular, a great deal of attention has focused on modifications to tax policy. However, to date, there is virtually no quantitative evidence both for the Canadian and U.S. economies of the impact of tax policy on R&D investment and inventive output production.

The objectives of this study are to:

1. Investigate the determinants of patent frequency. In particular, to focus on the role that factor prices, output and tax incentives exert on patenting behaviour.
2. Investigate the determinants of R&D and physical capital investment and labour requirements. In particular, to focus on the interrelationship between investment and patent frequency.
3. Develop a databank integrating the existing PATDAT information relating to corporations patenting and operating in Canada, along with their production, R&D expenditure and tax data.

2. INVENTION, INNOVATION AND PATENTS

The purpose of this chapter is two-fold. First we discuss the nature of inventing/innovating and the relationship to market structure and behaviour. Second we discuss the role of patents as devices which are used to internalize the spillover associated with knowledge output.

2.1 Knowledge Output and Tournaments

The output of the knowledge production process is considered the invention or innovation. Invention has been defined in many ways. According to some an invention is a prescription for a new product or process. Others add the requirement that the product or process must be 'useful' as well as 'novel'. Inventions occur in various ways as unexpected results may emerge. For example, a process for drawing brass rods arose from an adaptation of candle-making technology. Thus the attempt to solve a particular problem may result in solutions to what was once thought to be completely different problems. The implication is that the output of a knowledge producing process may more often than not be in reality a joint product situation.

An invention when applied for the first time is called an innovation. Usually, the distinction between invention and innovation is stressed because an invention has little 'economic' (i.e., social welfare) significance. This is, however, quite misleading. Not only is the distinction not clear, especially if the inventor/innovator is the same firm (as in the case of Du Pont's nylon), but inventive output involves its own 'economic

calculus'. The fact that inventors and innovators may not be the same economic agent is an observation worthy of explanation.

We can illustrate the nature of the 'invention game' by comparing it to a race. Suppose first that due to sunk costs (e.g., particular expertise) there is a monopoly inventor. This monopolist must decide the time it is going to take to produce an invention. Assume that the earlier the date the monopolist wants to produce the invention, the more resources that need to be applied to this task. Moreover, the invention lowers production costs, and the reward to the invention is fixed and independent of the time the invention occurs. Thus the monopolist determines the date of invention which balances the benefits of the reduction in production costs from bringing the invention forward in time with the resource costs of bringing forward the invention date.

Suppose this monopolist is now faced with a potential inventor, and that the outcome in the monopoly solution exhibited pure profits. The potential inventor by inventing at an earlier date can 'beat' the incumbent inventor. The costs of inventing will be higher than in the monopoly case but the invention date will be earlier. However, the incumbent inventor will respond by devoting even more resources to invention in order for it to occur at an earlier date than its rival. This competitive process will continue until all pure profits are dissipated. Indeed, it may be possible that this process will cause the invention to appear earlier than desirable, with an excessive amount of resources devoted to invention.

In the competitive discussion both inventors were similar (in terms of invention technology for example). If the incumbent inventor has costs which are sunk, so that there is a difference between the two inventors, the incumbent may be able to pre-empt the potential inventor. Sunk costs involve decisions relating to commodities which are both durable and irreversible. Sunk costs create an asymmetry between existing and potential inventors; they are hurdles over which the potential inventor must jump. In this context the monopolist inventor will be able to pre-empt rivals by devoting more resources to bring about the invention at an earlier date, such that it is not feasible for any rival to earn sufficient revenues to cover costs. Clearly, from the monopolist's vantage point this strategy dominates the competitive process because pure profits have not been dissipated. More significantly from society's point of view, this state of affairs may be superior to the competitive process because invention will not occur as early and fewer resources are being used in knowledge production due to invention postponement.

The characterization of invention races as tournaments implies that there is a 'winner' so that the winner is clearly identifiable, and the winner 'takes all' so that there is no neighbouring race for rivals to move to. Although invention competition has elements which fit the picture of a race, the analogy can be misleading. First, invention imitation is possible so that the winner does not take all. This is not, however, an important point since many tournaments are defined by the winner taking the major 'slice of the pie' but other participants can also reap

benefits. Second, and this is the most important reason, it is required that inventors face uncertainties that are independent of their efforts. This is not in general true. Firms can never be certain of being the winner, irrespective of the resources devoted to inventive activity, unless it can make it unprofitable for rivals to enter the race. In this case inventors will choose probability distributions whose parameters are affected by inventive effort (e.g., by the quantity of resources). This would result in the specialization of firms in knowledge production, for which they had a comparative advantage. Hence there may not be a single winner, but rather a continuum of winners.

2.2 Patents and Appropriability

Firms developing inventions may not be able to exclude other firms and rivals from freely obtaining the benefits of the innovation. This difficulty is called the 'appropriability or free-rider' problem.

The ability to exclude involves the (costly) use of scarce resources. In the case of innovation, exclusion costs are excessive, so that the benefits spill over to others in society. The implication is that if the innovator is not able to prevent free-riding then there may be an insufficient return on investment. The incentive to undertake innovation is diminished, and society may be facing a situation of insufficient innovation.

It is important to clarify the notion of innovation spillover or externality. When a firm purchases physical capital, embodied in

that capital is the innovation undertaken by the selling firm. This capital is part of the input requirements of the purchasing firm. These capital improvements are reflected in the market prices of the physical capital. If market prices fully reflect the benefits of the R&D then no spillover has occurred. All that has taken place is the diffusion of the innovation. Spillovers cannot be said to exist unless market prices have not completely captured the benefits from the innovation.

True spillovers are the ideas borrowed by firm i from the innovation of firm j. It is not clear that this kind of borrowing is particularly related to input purchase flows. The photographic equipment industry and the scientific instruments industry may not buy much from each other but may be, in a sense, working on similar things and hence benefiting much from each other's research.

Patent policy is designed to overcome the appropriability problem associated with knowledge production. To this end the production and diffusion of knowledge throughout the economy is facilitated. Patent policy relates to the output of the knowledge production process, in particular to inventions. A patent grants the patenter the sole right to make, use and sell an invention for a specific period of time (seventeen years in Canada). Recalling the definition of an invention, patents are applied to knowledge output which is new (not knowledgeable to those in the area, such that the idea is not publically used in Canada more than two years before the filing of the application and not disclosed elsewhere in the world) and useful (patents are issued for ideas which work and have industrial application).

A Canadian patent document includes the following information:

application number and date
issue number and date
patent classes
title of invention
name and country of residence of the inventor
name and country of residence of the patentee
priority date, country and application number
description of the invention
specific claims for the invention

We can observe that the holder of a patent is required to disclose a description of the invention including the nature of its operation as well as its uses, so that ambiguity can be avoided. In Canada information on the patent becomes available to the public when the patent is granted.

In 1981, 1,437 patents were granted for Canadian inventions to 935 applicants. However, this represents only approximately 10% of the total number of patents granted in Canada, which exhibits an unusual number of patents being granted for foreign inventions. Among the number of patents for Canadian inventions, roughly 33% of these patents were undertaken by 8% of the applicants. Table 2.1 presents the number of patentees, patents and the major corporate patentees.

Since patents are granted for inventions they are indicators of knowledge output. However, patents do not fully reflect all inventions. To see this, it is instructive to discern the avenues open to the inventor in the absence of patenting. First, the inventor may decide to disseminate the knowledge openly. This is the case of academic publication, where the return is enhanced reputation. However, the return is not greater than that under the patent system because the latter requires disclosure, and therefore permits the establishment of reputation.

Table 2.1

Patent Concentration in 1981

<u>Number of Patentees</u>	<u>Number of Patents</u>
1	>50
2	20-50
10	10-19
17	5-9
135	2-4
770	1
935	1,437

Major Corporate Patentees

Northern Telecom
 Can. Gen. Electric
 Imperial Oil
 Polysar
 Sherritt Gordon Mines
 Inco Ltd.
 Alcan
 Cominco
 Du Pont Canada
 General Foods Ltd.
 Westinghouse Canada
 Gulf Oil
 Domtar
 Dominion Engineering
 Dow Chemical of Canada
 Uniroyal Ltd.
 Mitel

Industry

Electronics, Electrical Products
 Electronics, Electrical Products
 Oil Extraction and Refining
 Chemicals and Rubber
 Mining and Smelting
 Mining and Smelting
 Alum. Smelting and Fabrication
 Mining and Smelting
 Chemicals and Rubber
 Food and Beverages
 Electronics, Electrical Products
 Oil Extraction and Refining
 Pulp and Paper, Chemicals
 Heavy Machinery
 Chemicals and Rubber
 Chemicals and Rubber
 Electronics and Electrical Products

Source: PATDAT, Department of Consumer and Corporate Affairs.

The previous comparison between open disclosure and patents is somewhat misleading for two reasons. First, publication is protected by copyright or by the social recognition of priority. Second, in order to enforce private property rights there must always be some form of protection. In fact there can be no private returns without protection, and therefore no inventions. As a consequence, the decision open to the firm is not between protection and no protection, but rather which type of protection. Moreover, the type of protection which emerges is the one which maximizes the inventor's net return. The realization of the reward depends on the inventor's capability to exclude prospective users, so that transactions can be made. The choice open to the inventor is between disclosure (patenting) or secrecy. The selection that emerges for any invention depends on the net benefits of secrecy versus the net benefits of patenting.

The characteristics of knowledge may lend itself to secrecy. For example, chemical formulas are not prey to copying. Specific cases would be that of Smith's Black Cough Drops which is over 100 years old, the Coca Cola syrup recipe and percussion cymbals like Zildjian, which have been family secrets for generations. Hence, we would expect to find that firms select the secrecy route when the invention is quite costly to discern through the product itself.

It is not only complex physical processes which lend themselves to secrecy, but also specialized human skills, such as gourmet recipes. In these instances the cost of imitation may be excessive.

Notice that there are two types of protection available to any invention -- secrecy or self-protection and patent protection. The benefit of keeping an invention secret is that other economic agents cannot imitate. However, there are also costs. Secrecy generates a weakly defined property right because the owner of the knowledge cannot exclude others from independently discovering the invention. Thus there are significant monitoring costs which must be undertaken in order to protect the secret. Second, there is the cost to the firm of not inventing because the potential inventor feels that the cost of successful copying may be lower than the cost of the original effort of inventing.

Clearly costs are incurred to protect the secret from disclosure. In contrast, it is precisely disclosure that patent protection offers. The costs of self-protection or in other words the costs of disclosure, are precisely the benefits of patent protection. The patent prohibits copying and so monitoring costs are not as great (a certain amount of policing is always necessary in order to detect patent infringement).

To protect an invention through a patent the firm must articulate the knowledge. This procedure delineates the right of the inventor. The process is difficult, and it is precisely in this situation where the costs of patent protection arise. A famous example of the costs of articulation is the first patent on J.W. Paige's typesetting machine, a three-ton monstrosity with 18,000 parts. The first application contained 204 sheets of drawings with 1,000 views. Later applications added 275 figures and 613 claims.

By selecting patent protection the inventor is disseminating the knowledge; to the extent that the inventor does not pinpoint the idea of invention, imitators can patent around the original patent. In general the lower the costs associated with patenting the more accurate will be patent statistics in indicating knowledge output, because few inventors will self-protect.

The number of patents (or inventions) is illustrated in Table 2.2. Here we see that although the number of patents in the early seventies were around 1,300 per year and the late seventies 1,500 per year the propensity to invent per 100,000 of the labour force has remained relatively constant at 14. Moreover, we find that institutions (of which corporations are a subset) have nearly twice the propensity to invent as do individuals.

Table 2.2
Canadian Patents

<u>Year</u>	<u>Patents</u>	<u>Labour Force</u>	<u>Patents Per 100,000 L.F.</u>
1973	1,259	9,358	14
1974	1,379	9,720	14
1975	1,309	10,054	13
1976	1,335	10,286	13
1977	1,270	10,578	12
1978	1,496	10,963	14
1979	1,501	11,287	13
1980	1,582	11,602	14
1981	1,437	11,911	12
Individuals	Average Annual		5
Institutions	Average Annual		9
Total	Average Annual		14

Source: H. Stead, Canadian Patent Statistics.

3. RESEARCH AND DEVELOPMENT EXPENDITURES IN CANADA

In current statistical summaries scientific and technological (S&T) activities are defined as those activities required for the generation, dissemination or initial application of new S&T knowledge. These activities are subdivided into two categories. The first is scientific research and experimental development (R&D) and related scientific activities (RSA). R&D is defined as, "creative work undertaken on a systematic basis to increase the stock of knowledge...and to use this knowledge in new applications." Examples of R&D encompass: the development of new methods of identifying tree species; and, investigating the factors determining regional variations in unemployment.

There are a number of activities related to R&D which are referred to as RSA. For example, scientific data collection, information services, testing, feasibility and policy studies.

In general S&T activities pertain to a production process of knowledge generation. This process involves a number of different inputs and outputs. Moreover, the situation is rendered more complex by the fact that the process of knowledge production is embedded into the production process of other saleable products. More specifically S&T activities relate to the various inputs in the production of knowledge.

Let us now turn to the trends of S&T activities, or the inputs in the knowledge production process. A basic indicator of R&D at the national level is the gross domestic expenditure on R&D performed on the national territory during a given year

(GERD). This measure includes R&D performed within a country irrespective of the source of funding. Table 3.1 illustrates the aggregate R&D expenditures in Canada over the previous decade. An interesting observation is that although GERD has been monotonically increasing, the proportion of R&D expenditures out of GDP was steadily falling over the decade of the seventies, from a high of 1.35 in 1971 to a low of 1.05 in 1976. This amounted to a decrease of 22%. The average propensity to spend on R&D fell by over 20% in the first half of the decade. However, this propensity increased in the last half of the 1970's so that the decline over the complete decade was 17%.

The total value of R&D does not highlight the spread of the activities throughout the Canadian economy. Table 3.2 illustrates the breakdown of intramural R&D by sector. We can observe that each sector has been increasing its expenditures on R&D over the period 1971-1982. The total amount of R&D has increased by 267%, in nominal terms from 1971-1982. The government sector's R&D expenditures grew by 197% and the non-government sector expanded by 299%. In 1971 the government composition of R&D was 31% compared to 25% in 1982. Hence we can see from Table 2.2 that R&D expenditures grew at a more rapid rate for the non-government sectors.

Focusing more directly on the composition of the non-government sector, we find that in 1971 the business enterprise sector comprised 51% of the R&D expenditures and in 1971 64%. This compares to 48% and 35% for higher education. Clearly the growth in R&D expenditures is rising relatively more in the non-government sector, in particular in business enterprises.

Table 3.1
R&D in Canada

<u>Year</u>	<u>GDP</u> <u>\$000,000</u>	<u>GERD</u> <u>\$000,000</u>	<u>GERD/GDP</u> <u>%</u>
1971	96,961	1,311	1.35
1972	108,780	1,344	1.24
1973	128,164	1,443	1.12
1974	151,570	1,689	1.11
1975	170,681	1,900	1.11
1976	195,774	2,064	1.05
1977	215,066	2,302	1.07
1978	238,465	2,609	1.09
1979	265,912	2,965	1.12

Source: R&D Expenditures in Canada 1963-1982, Cat. Pub.
SS82-5.

Table 3.2
Performers of R&D by Sector

Sector	Year											
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	-\$000,000											
Total Government	407	445	485	553	592	638	688	770	783	898	1,031	1,208
Federal	368	399	430	485	520	556	598	673	669	757	880	1,040
Provincial	39	46	55	68	72	82	90	97	114	141	151	168
Total Non-Government	904	898	958	1,136	1,310	1,426	1,615	1,839	2,183	2,535	3,052	3,607
Business Enterprise	464	459	503	614	700	755	857	1,007	1,273	1,500	1,895	2,309
Higher Education	432	430	445	511	598	658	741	812	888	1,007	1,127	1,263
Private Non-Profit	8	9	10	11	12	13	17	20	22	28	30	35
Total	1,311	1,343	1,443	1,689	1,902	2,064	2,303	2,609	2,966	3,433	4,083	4,815

Source: R&D Expenditure in Canada 1963-1982, Cat. Pub. SS82-5.

We have seen how the business enterprise sector is a significant contributor to R&D activities in Canada. Hence we now turn our attention to a deeper look at industrial R&D statistics. First Table 3.3 illustrates intramural industrial R&D expenditures in current and constant 1971 dollars. In addition the data are broken down into current and capital expenditures. In constant 1971 dollars industrial R&D has grown from \$464 million in 1971 to \$943 million in 1982 for an increase of 103%. Generally, current expenditures in 1971 dollars comprises 85% of R&D expenditures in 1971 dollars and this percentage has remained fairly stable.

This study looks at the effect of tax policies for various companies operating in different industries. Consequently, we are also interested in the R&D picture on a cross-section basis. Table 3.4 shows R&D expenditures by company sales size from 1973 to 1981. Clearly, the large firms undertake the vast majority of industrial R&D. Moreover, over the last decade the R&D performers have become even more concentrated in the \$50 million or more group.

The significance of the recent R&D trends is further highlighted by the recent Financial Post R&D survey which sent out questionnaires to 88 firms, 82 of which answered some or all of the queries. From this survey, the R&D expenditures are detailed in Table 3.5 for 1981, 1982 and the projected expenditures for 1983.

According to this survey the private sector firms will spend \$1.258 billion in Canada on R&D in 1983 or a 12% increase from 1982. In addition, the Crown agencies will spend \$370 million, which is 17% more than 1982 and substantially above

Table 3.3

Sources of Funds for R&D by Sector*

Sector	Year											
	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Total Government	642	688	751	830	888	964	1,060	1,180	1,220	1,404	1,678	1,949
Federal	578	609	656	722	767	817	889	993	1,009	1,159	1,405	1,647
Provincial	64	79	95	108	121	147	171	187	211	245	273	302
Total Non-Government	670	656	693	868	1,013	1,100	1,243	1,426	1,744	2,028	2,407	2,866
Business Enterprise	365	360	393	500	575	616	698	843	1,066	1,260	1,586	1,954
Higher Education	260	248	246	297	368	405	451	487	536	576	616	685
Private Non-Profit	18	19	20	26	26	32	38	43	53	66	76	88
Foreign	-	29	34	35	44	47	56	53	89	126	129	139
Total	1,312	1,344	1,444	1,688	1,900	2,064	2,303	2,606	2,963	3,432	4,085	4,815

Source: R&D Expenditures in Canada 1963-1982, Cat. Pub. SS82-5.

*Total figures differ between Tables 2.2 and 2.3 because of rounding.

Table 3.4
Industrial R&D Expenditures
by Company Sales Size

<u>Size - \$000,000</u>	<u>Year</u>				
	<u>1973</u>	<u>1975</u>	<u>1977</u>	<u>1979</u>	<u>1981</u>
1	5	4	4	2	2
1 - 9.9	9	8	7	6	6
10 - 49.9	20	17	12	10	10
50	61	65	71	79	80

Source: Standard Industrial R&D Tables 1963-1983, Cat. Pub.
SS83-3.

Table 3.5

Major Firms R&D Expenditures

	1983 Projected	1982	1981
	-----\$ million-----		
Bell Canada	406	336	264
Atomic Energy of Canada	179.2	155.9	131.6
Pratt & Whitney Aircraft of Canada*	130	118	113
Hydro-Quebec	106	67	60
Canada Development	75	79.6	58.2
Ontario Hydro	60	65	55
Alcan	59.3	48.5	41.4
Mitel	55	30.5	23
Imperial Oil	56	51	56
IBM Canada	..	35	22
General Motors of Canada	29.4	30	24.5
CIL	27.9	25.8	25.7
Shell Canada	24	20	17
B.C. Telephone	22	19	17
CAE Industries	19	19.4	19.2
Cdn. General Electric	..	18	23
NCR Canada	16.6	16.6	13
Inco	16	19.7	22.2
Noranda	16	15.2	12.7
Nova	15	10	14
Nabu	15	11	2.6
Syncrude	14.7	17.5	12.6
Canadair	12.1	14.3	46.6
Control Data Canada	12	11.9	10.4
Du Pont Canada	12	11.9	10.1
MacMillan Bloedel	11.6	13.5	17.4
Dow Chemical of Canada	11	10.6	10.9
Stelco	9.6	9.1	9.9
Honeywell Ltd.	9.4	9.2	6.2
Xerox Canada	9	8.2	7.5
Mobil Oil Canada	8.6	3	4.3
Litton Systems Canada	7.1	8.8	2.9
Massey-Ferguson	6.6	7.4	6.5
Fiberglas Canada	6.4	5.9	5.2
General Foods Inc.	6.4	6.6	6
Abitibi-Price	6.2	5	6.6
Electrohome	6.1	6.3	3.8
Gandalf	6	4.2	2.8
Canada Packers	..	5.6	5.1
Suncor	..	5.5	7.1
Johnson & Johnson Ltd.	4.9	3.7	3.4
Sherritt Gordon	4.6	4.9	5.6
John Labatt	4.4	4	3.8
George Weston	4.3	4	3.3
Falconbridge Ltd.	3.8	5.4**	11.1
Canadian National	3.5	3.5	3.5
Consolidated Bathurst	3.5	3.4	3.2
Potash Corp. of Sask.	3.4	4.2	3.8
Systemhouse	2.8	9.6	10.6
Atla. Govt. Telephones	2.6	2.8	2.7
Ingersoll-Rand Canada	2.6	2.9	1.1

Source: Financial Post R&D Survey

*Includes repayable government grants

**Estimate

the 3.7% increase between 1981 and 1982. However, there are some difficulties associated with the R&D activities. R&D employment for 23 firms and Crown agencies decreased by 695. For example, mining and forest products are registering \$68 million for R&D in 1983 compared to \$85.8 million in 1981 and 175 R&D employees have been laid off. Of equal importance is the fact that 65 firms have increased their R&D capital expenditures, even some of those that have trimmed their work force. Thus we may see that R&D activities are becoming more capital intensive. This may not be troublesome for R&D labour (in absolute terms) as long as R&D activities exhibit a secular rise, since some firms are also finding it difficult to hire engineers and scientists.

A finding of the survey was that most firms would like to see even more generous R&D tax credits, and greater incentives for the exploitation of R&D activities. The view which is consistent with the theme of this study, necessitates that firms cannot hire off their R&D activities, but must more fully integrate this area with product demand conditions and plant and equipment expenditure decisions. It is not possible to fully understand R&D and patent decisions, as well as the impact of government policy, without appreciating the related corporate output and input requirement decisions.

The conclusions of this chapter are that there has been a considerable increase in R&D expenditures in Canada over the last decade. However, as a percentage of GDP the average propensity to undertake R&D has fallen. Second, the rate of increase varied considerably over the different sectors. For example,

the business enterprise sector's R&D growth rate was above average, while that for higher education was below the average growth rate. In addition, the business enterprise sector, in actual dollars, remained the largest performing R&D sector.

Within the business enterprise sector R&D expenditures consist mainly of current expenditures and the composition between current and capital has remained quite stable. In addition, R&D performance continues to be concentrated in firms with sales of \$50 million or more and the degree of concentration has been increasing over time.

4. TAX POLICY, AND RESEARCH AND DEVELOPMENT

The purpose of government policy relating to patents is to help the knowledge producer (i.e., the inventor) appropriate the benefits. We have seen that because knowledge production generates 'spillover effects' between economic agents, appropriability may be a problem. Patent policy is designed to help the inventor 'internalize' the externality. Tax policy, however, re-arranges the rules that the private sector operates under, not with the objective of aiding this sector, itself, to internalize the spillover, but rather to counter the effects of the externality. Hence under tax policy the externality persists but may be offset by public sector policy.

4.1 Specific Tax Incentives

Table 4.1 presents a brief history of Canadian R&D tax policy. We can observe from this table that the R&D tax policy relevant to the sample period of 1975-1980 was:

1. Current and capital R&D expenditures can be deducted in the year they were incurred or in any year thereafter.
2. Current and capital R&D expenditures incurred in the current year are eligible for a tax credit which ranges from 10-25 per cent depending on the region of the country and the size of the corporation. Deductible R&D expenditures are reduced by the amount of the credit.
3. There is an additional tax allowance of 50 per cent of the current year's current and capital expenditures in excess of the average of the three preceding years. This is deductible from the current year's taxable income.

Table 4.1

Brief History of Canadian R&D Tax Policy

- Pre-1961 Current expenditures on R&D were made wholly deductible in the year in which they occurred.
- One-third of the capital expenditures on R&D during the year and the two preceding years were deductible in the current year.
- The total deduction for R&D was not to exceed 5 per cent of the previous year's taxable income unless the expenditures were approved by the Department of National Revenue.
- 1961 Capital expenditures were made fully deductible in the year incurred or any year thereafter.
- 1962 Requirement for approval by authorities of expenditures in excess of 5 per cent of previous year's taxable income was eliminated.
- 50 per cent of an increase in R&D expenditures (current or capital) over the base, defined as expenditures in 1961, was deductible from taxable income.
- 1967 The 50 per cent deduction for all R&D expenditures in excess of the 1961 base was replaced by grants under the Industrial Research and Development Incentives Act (IRDIA). This act provided a cash grant of 25 per cent of capital expenditures and 25 per cent of current expenditures in excess of the average expenditures made during the base period. The latter period was defined as the five years preceding the grant year. The 25 per cent cash grant was non-taxable.
- 1975 The deferral privilege for capital R&D expenditures was extended to current expenditures. Now both current and capital R&D expenditures could be written off in the year they were incurred or any year thereafter.
- 1976 IRDIA repealed.
- 1977 R&D investment tax credit introduced. The credits ranged from 5-10 per cent depending on the region. The credits were based on all R&D expenditures. The 10 per cent credit was granted for Atlantic provinces and the Gaspé area of Quebec.
- 1978 R&D investment tax credits were doubled and a credit of 25 per cent for small businesses was introduced.
- An additional tax allowance of 50 per cent of total R&D expenditures in excess over the previous three years was introduced.

Table 4.2 presents the distribution of tax policies for R&D in 1982. The total of \$205 million represents about 5 per cent of industrial R&D performed in 1982. The federal government provides about 85 per cent of the total support. The provincial governments share in the cost of the 100 per cent deduction and the 50 per cent additional allowance, however this cost is offset by the tax credit they receive from the federal government. This occurs because the federal credit reduces the base for the purpose of calculating the base for the 100 per cent deduction. This, in turn, increases taxable and thereby increases the provincial tax revenues.

The ability of firms to utilize the various tax incentives available to them involves a number of issues. A firm without taxable income will not benefit from the immediate write-off provision, the tax credits and allowances. Moreover, a firm with taxable income, but not of significant magnitude to use all the deductions, credits and allowances faces a number of possibilities. First, if R&D expenditures must be expensed in the current year and there are no provisions for transferring unused deductions, credits and allowances, the firm will not completely benefit from the tax policy. Second, if current or capital expenditures could be deducted from taxable income at any time in the future, or if capital expenditures must be amortized or if there are carry back or carry forward provisions or if unused deductions, credits and allowances can be transferred (through, for example, a market for these items which could take on various institutional forms as the Scientific Research Investment Contracts) then tax policy benefits are enhanced.

Table 4.2

Distribution of Government Tax Policy for R&D in 1982

Support	Level of Government		
	Federal	Provincial	Total
	-----\$000,000-----		
Tax value of 100% Deduction	60	20	80
Tax Value of Credit	80	(15)	65
Tax Value of Additional Allowance	45	15	60
	—	—	—
Total	185	20	205

Source: Research and Development Tax Policies, Department of Finance, p. 5.

Each of these issues differ by the flexibility they allow the R&D performer. For example, in the absence of transfer ability, carry over provisions may not permit the firm to take full advantage of tax policy (i.e., to enhance its cash flow position) if they are not effective collateral in the financial capital markets.

Table 4.3 provides information on how R&D performers take advantage of the tax incentives in 1980. First, we can observe that 31 per cent of R&D was performed by firms who did not have sufficient taxable income to fully utilize the available benefits. In particular, they could not use any of the R&D investment tax credit. Second, 38 per cent of R&D has been undertaken by firms who could not use all of their tax credits. Therefore, nearly 70 per cent of all R&D performers could not use all of their benefits.

The utilization of tax benefits varies across firms. Table 4.4 provides information on the distribution of firms by asset size and the degree to which the tax incentives were not utilized in 1980. A number of implications emerge. First, most of the smaller firms are in the non-taxable category and consequently do not make any use of the tax incentives. Second, mid-size companies, although one third of them are non-taxable, use most of their tax incentives. Tax incentives are most fully utilized in the \$10-\$49 million range. The problem is that this class accounts for only 10 per cent of industrial R&D. Third, the largest size of company accounts for over 70 per cent of R&D, and only one fifth fall into the non-taxable category, yet 60 per cent of their tax incentives are not utilized. The problem is that with respect to the R&D investment tax credit, only \$15,000 could be claimed without limit. Consequently, the large-size firms hit the dollar

Table 4.3

Corporate Tax Status and R&D in 1980

	Per Cent of R&D
Taxable Companies	
No limits on tax credit	31
Limits on tax credit	38
Total	69
Non-Taxable Companies	
Profitable	19
Non-Profitable	12
Total	31

Source: Research and Development Tax Policies, Department of Finance, p. 15.

Table 4.4
Company Utilization of Tax Incentives in 1980

<u>Size of Assets \$Millions</u>	<u>Per Cent of R&D by Non-Taxable Firms</u>	<u>Per Cent of Unutilized Incentives</u>	<u>Per Cent of R&D Performed</u>
<1	91	22	11
1-9	48	13	8
10-49	32	5	10
>50	20	60	71
Total	31	100	100

Source: Research and Development Tax Policies, Department of Finance, p. 16.

constraint imposed on the tax credit, and therefore the potential cash flow benefits to the major R&D undertakers is hampered.

4.2 Assessing the Tax Incentives

To evaluate the tax incentives described previously, it is necessary to estimate their effects. For example, consider the special tax allowance applicable to R&D. We would like to estimate the additional R&D that would result from an increase in the tax allowance rate. In addition, we would like to determine whether and how investment in plant and equipment and labour requirements are influenced by the increase in the rate.

Since there is no quantitative evidence of the effectiveness of tax incentives on R&D, analogies to physical investment are often made. There are essentially two specific means (through tax policy) by which the government influences physical capital investment; tax credit and accelerated depreciation. The tax credit is the same that applies to R&D expenditures. In addition, expensing all R&D expenditures, irrespective of whether they are current or capital, is a form of accelerated depreciation (with a depreciation rate for tax purposes equal to unity). However, the depreciation rate on plant and equipment for tax purposes is less than unity.

Studies of the effects of tax incentives on plant and equipment investment have found that there is a stimulating influence, but estimates differ as to their size and permanence. Hall and Jorgenson [1967], [1971] estimated for the U.S. that

during 1962-1970 the tax credit increased physical capital investment by about \$3 billion (1965 dollars) per year, and accelerated depreciation caused a \$1 billion (1965 dollars) per year increase. Bischoff [1971], in a somewhat different specification of the production process than the one employed by Hall and Jorgenson, found that the tax credit increased equipment expenditures by about \$2-\$2 billion (1958 dollars) per year in the mid 1960s, but accelerated depreciation only generated \$0.7 billion (1958 dollars) in equipment investment.

Lastly, Coen [1971], introducing a form of adjustment costs, found that both the tax credit and accelerated depreciation had almost no influence on plant and equipment expenditures. Thus, as Eisner and Nadiri [1968] have noted the effects of the tax incentives depends on the specification of the technology (in particular the elasticity of substitution) and the nature of the adjustment process. Indeed, in order to overcome the limitations of the previous work, in the present study we specify both the technology and adjustment costs in terms of flexible functional forms. Thereby permitting various degrees of factor substitution and speeds of adjustment.

Besides the analogy arguments that may (or may not) be made concerning the tax incentives on physical and knowledge capital, there is another reason for studying the effects of tax policy on physical capital investment. Investment in plant and equipment also affects the rate at which new technology is introduced, since many kinds of technological advances cannot be applied unless they are accompanied by physical capital expansion. It

may be the case that in certain circumstances physical and knowledge capital are complementary factors. In such cases tax policy which stimulates the rate of investment in plant and equipment, also causes an indirect effect on the rate of R&D investment. Evidence of this relationship has been known since the mid 1960s (see Schmookler [1966]).

It is often not recognized that investment in R&D also affects the rate at which plant and equipment expansion occurs. If a firm is undertaking knowledge capital growth, it may be the case that more physical capital is needed in the new process or to produce the new product. As a consequence tax incentives which directly influence the rate of knowledge investment, indirectly affect the plant and equipment growth rate. Hence the interrelationship between the investment rates for both types of capital may be simultaneous rather than the hitherto accepted hypothesis of recursivity. In the present study we want to estimate the interrelationship between the investment rates, and thereby test the complete set of indirect and direct effects. In order to carry out this task we consider each type of investment as being determined (in part) by past accumulations of both knowledge and physical capital, as well as rental rates on the capital stocks.

5. The Databank

The data gathering process involved a rather detailed and complex set of steps. First, we were interested in corporate data, so that the sample would consist of a pooled set of cross section and time series. The corporate data would provide disaggregated information on the determinants of factor demands, and the effectiveness of tax incentives. This is generally not the basis for most studies on investment behaviour, which are related mostly to the manufacturing sector.

The second task is related to the selection of the corporations under consideration in the study. The criteria for this selection centred around a number of characteristics. The companies had to be private sector public corporations, they had to incur their intramural R&D expenditures in Canada (although they could be either Canadian-owned or foreign subsidiaries), they had to sell their products in Canada (they could also, of course, export), and finally their sales had to be \$50 million or greater.

The legal status and sectoral criteria enable us to develop a complete data set for each corporation as financial reports are readily available for public corporations. In addition, since large firms tend to have more data collected on their activities we selected firms with sales of \$50 million or more. More importantly, however, because we are pooling time series and cross section data, and since there is an inadequate span of time series data that would permit us to test the manner in which to combine the various firms, we wanted to

have some semblance of similarity across the firms. Using sales size (in this case of \$50 million or greater) is a usual technique (see Nadiri and Bitros [1980]). Furthermore in the present context by only limiting the lower bound on sales size, the restriction is quite weak or mild.

We are concerned with firms operating in Canada. Hence we require that any firm in the sample must sell some of their output, as well as undertake their R&D in Canada. For our purposes these latter criteria define as tightly as necessary the concept of Canadian operations. It turns out that the characteristics of our sample tend to be complementary. Large firms are generally public corporations which sell their products and undertake R&D in Canada.

A number of different data sources were involved. First, a subset of the PATDAT tape from Consumer and Corporate Affairs was developed. This tape was defined for patents which were undertaken by public companies operating in Canada. The list of companies and their designated brids are given in Table 5.1.

The PATDAT databank only gave us the number of patents and the year they were granted. For the data regarding sales, assets and expenses of various types we drew upon the CALURA tapes of Statistics Canada. A number of problems arose here. The CALURA records have changed over time and also some gaps appeared in these records in the early 1970s. These two problems were solved by defining the time series as 1975-1980.

A third problem centred on the fact that a company may select various subsidiaries under which to undertake the R&D, while the parent or some other subsidiary may be the major source of sales.

Table 5.1

<u>Company Name</u>	<u>PATDAT Brid</u>
1. Electrohome Limited	80542624
2. Polysar Limited	81354862
3. Sherritt Gordon Mines Limited	81543357
4. Domtar Company Limited	82373036
5. Alcan Research and Development Limited	82845538
6. Bombardier Limited	82864430
7. Canadian International Paper Co.	82874066
8. Northern Electric Co. Ltd.	82994112
9. Macmillan Bloedel Limited	90001769
10. Inco Limited	90007048
11. Cominco Ltd.	90012683
12. Northern Telecom Limited	90033036
13. Canada Wire and Cable Limited	80156516
14. Steel Company of Canada Limited	90004086
15. Consolidated Bathurst Inc.	90006552
16. Canada Packers Ltd.	90011297
17. International Nickel Co. of Canada Ltd.	82942087
18. Aluminum Company of Canada, Ltd.	90008368

Table 5.1 cont'd.

<u>Company Name</u>	<u>PATDAT Brid</u>
19. Canadian General Electric Company Ltd.	80282734
20. Great Canadian Oil Sands, Ltd.	80715865
21. Imperial Oil Ltd.	80828858
22. Union Carbide	90003245
23. Du Pont of Canada Limited	81973430
24. Dominion Engineering Works, Limited	82898826
25. Uniroyal Ltd.	85003473
26. Canada Cities Service, Ltd.	90000522
27. International Harvester Co. of Canada Ltd.	90003732
28. Fiberglass Canada Ltd.	90006685
29. General Foods Ltd.	90006974
30. Du Pont Canada Inc.	90010448
31. Westinghouse Canada Ltd.	90042375
32. International Harvester Canada Ltd.	90289323
33. Imperial Oil Enterprises Ltd.	50005198
34. General Foods Inc.	50023159
35. Canadian Westinghouse Co. Ltd.	90000548
36. General Foods Inc.	90282583
37. Honeywell Limited	90006461
38. RCA Limited	90007345
39. Texaco Exploration Canada Ltd.	90023615
40. Texaco Canada Inc.	90167164

In these situations we aggregated the legal enterprises into a single economic entity by simply defining both the sales and R&D expenditures (for example) as pertaining to a single firm. Specifically, if different subsidiaries carried out R&D we aggregated these expenditures. Moreover, there was no problem with double-counting since we only considered intramural R&D expenditures in the sample. Any transactions between subsidiaries would always be counted only once because we are adding the R&D expenditures of the performers.

The R&D Data Tape of Statistics Canada was the source of the R&D expenditures, tax credits and other R&D related variables. Thus, besides the difficulty of developing such a large consistent set of data at the firm level, there was the task of merging three different data tapes. The three other sources of data were; the CANSIM tapes for the two digit wage rate and producer price indexes; the National Bureau of Economic Research for the equity rate of return, the bond interest rate and the R&D deflator (see Cummins, Hall and Laderman [1982]).

The list of firms, their CALURA T2 numbers, R&D Data Tape numbers and two-digit SIC codes are listed in Table 5.2.

We now describe the manner that we derived variables 26-36 which are listed in Table 5.3. The formulas used to derive variables 26-37 are given in Table 5.4 First (variable 26) from the net fixed assets and depreciation, we arrive at plant and equipment (P&E) expenditures, and then P&E investment is obtained by deflating by the price index. The average age of P&E (the inverse of this is the depreciation rate) is derived

Table 5.2
Companies Selected

<u>Name</u>	<u>CALURA T2 No.</u>	<u>R&D Tape No.</u>	<u>SIC</u>
1. Electrohome Limited	2845312	0071	61
2. Polysar Limited	5512960	0014	26
3. Sherritt Gordon Mines Limited	6135504	0029	42
4. Aluminum Company of Canada Limited	1212096	0007	42
5. Bombardier Limited	1643547	0026	53
6. Canadian International Paper Co.	1956764	0031	33
7. Northern Telecom Ltd.	5133888	0001	63
8. Macmillan Bloedel Ltd.	4547793	0032	33
9. Inco Limited	3838288	0004	42
10. Cominco Ltd.	2300319	0025	11
11. Canada Wire and Cable Ltd.	1528296	0743	61
12. Steel Co. of Canada Ltd.	6348624	0022	41
13. Consolidated-Bathurst Inc.	2336708	0063	33
14. Canada Packers Inc.	7333334	0040	21
15. Canadian General Electric Company Limited	1956316	0002	61
16. Great Canadian Oil Sands Ltd.	3403864	1867	12
17. Imperial Oil Limited	7949599	0005	24
18. Union Carbide Canada Limited	7851480	0059	26
19. Du Pont Canada Inc.	2705055	0009	26
20. Dominion Engineering Works Ltd.	2646049	0053	51
21. Uniroyal Ltd.	6723400	0027	22
22. Canada Cities Services Ltd.	7199298	1691	12
23. International Harvester Company of Canada	3836316	0039	51
24. Fiberglass Canada Ltd.	3029440	0066	71
25. General Foods Limited	3245152	0068	21
26. Westinghouse Canada Limited	7198771	0018	61
27. Honeywell Limited	3685824	1032	62
28. RCA Ltd.	5725530	0035	63
29. Texaco Canada Inc.	7851299	1842	24

Table 5.3

Variables

<u>No.</u>	<u>Name</u>	<u>Source*</u>
1.	Sales, Products	C, H1
2.	Sales, Services	C, H9
3.	Salaries and Wages	C, G12
4.	Employee Benefits	C, G14
5.	P&E Investment Tax Credit	C, K38
6.	Net Fixed Assets	C, E21
7.	Total Depreciable Assets	C, E19
8.	Depreciation and Amortization Expense	C, G23
9.	Net Long Term Debt	C, F23
10.	Intramural R&D Current Exp. (Wages and Salaries)	R, 301-306
11.	Intramural R&D Current Exp. (Other Current)	R, 307-312
12.	Intramural R&D Capital Exp. (Land)	R, 313-318
13.	Intramural R&D Capital Exp. (Bldg.)	R, 319-324
14.	Intramural R&D Capital Exp. (Mach.)	R, 325-330

-
- * C represents CALURA and the following designation shows the position
 R represents R&D Tape and the following designation shows the position
 D represents derived
 A represents the CANSIM Tape
 N represents the NBER R&D Tape
 O represents other.
 P represents PATDAT.

Table 5.3 cont'd.

<u>No.</u>	<u>Name</u>	<u>Source</u>
15.	Employment	R, 584-590
16.	R&D Investment Tax Credit	R, 917-922
17.	Wage Index	A
18.	Producer Price Index	A
19.	Equity Rate of Return	N
20.	Bond Interest Rate	N
21.	R&D Deflator	N
22.	P&E Deflator	A
23.	Statutory Corporate Income Tax Rate	O
24.	Present Value of Capital Consumption Allowance	D
25.	Patents	P
26.	P&E Expenditures	D
27.	P&E Investment	D
28.	P&E Average Age	D
29.	R&D Investment	D
30.	Output	D
31.	Average Rate of Growth of Output	D
32.	R&D Capital Stock	D
33.	P&E Capital Stock	D
34.	Labour Input	D
35.	R&D Tax Allowance	D
36.	P&E Rental Rate	D
37.	R&D Rental Rate	D

Table 5.4
Derived Variables

<u>Variable</u>	<u>Formula</u>
26(t)	= Var6(t) - Var6(t-1) + Var8(t)
27(t)	= Var23(t)/Var22(t)
28	$= \sum_{t=75}^{80} [\text{Var7}(t) - \text{Var6}(t)] / \text{Var8}(t) \cdot 6]$
29(t)	= [Var10(t) + Var11(t) + Var12(t) + Var13(t) + Var14(t)] /Var21(t)
30(t)	= [Var1(t) + Var2(t)]/Var18(t)
31	$= \sum_{t=76}^{80} [\text{Var30}(t) - \text{Var30}(t-1) / \text{Var30}(t-1) \cdot 5]$
32(1975)	= Var29(1975)/(.1 + Var31)
32(t)	= Var29(t) + .9 Var32(t-1) t = 1976-1980
33(1975)	= Var27(t)/[(Var28) ⁻¹ + Var31]
33(t)	= Var27(t) + [1-(Var28) ⁻¹]Var33(t-1) t = 1976-1980
34(t)	= [Var3(t) + Var4(t)]/Var17(t)
35(t)	= .5 [Var29(t)·Var21(t) - $\sum_{s=t-1}^{t-3} \text{Var29}(s) \cdot \text{Var21}(s)$]/3] t = 1978-1980
36(t)*	= Var22(t) [Var19(t) + (Var28(t)) ⁻¹] [1 - (Var5(t)/Var26(t)) - (Var24(t)·Var23(t))(1-Var5(t)/Var26(t))]
37(t)	= Var21(t) [Var19(t) + .1] [1-Var23(t)) (1-(Var16(t)/ Var29(t)·Var21(t)) - (Var35(t)/Var29(t)·Var21(t))]

*The formulas for the rental rate on P&E and R&D are the outcome of the dynamic optimizing model presented in Chapter 5.

by finding the average difference between the gross and net fixed assets per dollar of depreciation. Next R&D investment is the sum of intramural expenditures divided by the price index and output is total sales divided by its price index. With an assumed depreciation rate of 10%, and initializing R&D capital, by dividing P&D investment by the sum of the depreciation rate and the average rate of growth of output, we obtain R&D capital through the declining balance formula. For P&E capital we also use the declining balance formula, with initial investment expenditures deflated by the P&E price index. The labour input was simply derived by dividing the labour expenses by the wage index. The R&D tax allowance (which is applicable from 1978-1980) is 50% of the excess of current R&D expenditures over the average of the last three years of nominal R&D expenditures. Finally the formulas for the rental rates on R&D and P&E capital will be explained in the chapter on the development of the model.

6. THE THEORETICAL MODEL AND EMPIRICAL SPECIFICATION

The purpose of this chapter is to develop and estimate the model from which various elasticities and tax policy effects will be determined. The essential ingredients of this model are that:

1. It is dynamic in its theoretical foundations, so that costly adjustment to changes in the stocks of physical and knowledge capital are included in the corporate optimizing solution and not introduced on an ad hoc basis.

2. It integrates knowledge outputs (inventions) and knowledge inputs (R&D) into a framework with a firm's decisions on labour hiring and physical capital accumulation. The key here is that R&D and inventions are not analyzed independently from other aspects of production and investment. As Mansfield et al. noted (Research and Innovation in the Modern Corporation, p. 10): "...the effectiveness of a firm's R&D department depends heavily on its relations with other parts of the firm".

3. Financing and investment decisions are integrated. This permits us to investigate whether a firm finances plant and equipment (P&E) investment in a distinct manner from research and development (R&D) investment.

4. Tax parameters are introduced into the optimizing solution. Accelerated depreciation on P&E, the P&E investment tax credit, the R&D investment tax credit, the incremental R&D investment allowance and the R&D write-off provisions are included in the analysis. This permits us to discern the effects of each of the policy instruments, as well as to capture the interrelationship

For example, we can determine the impact that the P&E investment tax credit exerts on R&D investment and patent decisions.

The outline of this segment of the study is as follows. In the proceeding section the theoretical model is detailed, where we pay particular attention to the role of the various tax instruments in the dynamic model. In this section we also present the dynamic dual to the model, and discuss how we can represent the corporate plan from this vantage point. Lastly, we discuss the empirical implementation based on the dynamic duality representation.

6.1 Theoretical Development

Consider a firm whose production process can be represented as

$$(6.1) \quad T(y_1(t), y_2(t), L(t), K_p(t), K_r(t), I_p(t), I_r(t)) = 0,$$

where $y_1(t)$ and $y_2(t)$ are non-inventive and inventive output respectively, T is the twice continuously differentiable transformation function, $L(t)$ is labour services, $K_p(t)$ is physical capital services, $K_r(t)$ is knowledge capital services, $I_p(t)$ is physical capital investment and $I_r(t)$ is knowledge capital investment. The variable t represents the time period and for ease of notation we drop it when no ambiguity arises. The marginal products are positive and diminishing for the factors

of production. The adjustment costs associated with the capital stocks are internal. Following Treadway [1971], [1974], Mortenson [1973], we assume that the quasi-fixed factors (i.e., the capital services) are subject to increasing internal costs of adjustment. This means that as purchases of additional units of each quasi-fixed input occur, the quantity of foregone output rises. Consequently, the average cost of investment increases in response to physical and knowledge capital accumulation.

The capital stocks accumulate by

$$(6.2) \quad \dot{K}_i = I_i - \delta_i K_i \quad K_i(0) = K_i^C > 0 \quad i = p, r$$

where δ_i is the fixed depreciation rate of the i^{th} capital stock. We assume that the firm is a price-taker in all markets and hence the flow of funds can be written as

$$(6.3) \quad p^T y - wL - p_p I_p - p_r I_r + \dot{B} - r_b B - T_t = D - p_s \dot{N}$$

where p is the product price vector, $y = (y_1, y_2)$, w is the wage rate, p_i is the price of the i^{th} capital stock $i = p, r$, B is the value of corporate debt, r_b is the bond interest rate, D represents dividends, p_s is the share price,

N is the number of shares, and T_c are corporate taxes. We assume static expectations on the prices and the interest rate. Defining the left side of (6.3) as Γ , which is the net flow of funds to shareholders, we can rewrite (6.3) in terms of the value of shares,

$$(6.4) \quad \dot{S} + \Gamma - \rho S = 0,$$

where $S = p_S N$, and $\rho = (D/p_S N) + \dot{p}_S/p_S$ is the cost of equity capital. Assuming that the payout ratio is fixed, and since there is static expectations on the share price, then static expectations prevail on the cost of equity capital.

The solution to equation (6.4) yields the present value of the firm's equity

$$(6.5) \quad S(0) = \int_0^{\infty} e^{-\rho t} \Gamma(t) dt.$$

We assume that the firm operates in the interest of the shareholders, and therefore the objective is to maximize $S(0)$. The firm fulfills this goal by selecting labour requirements, investment in physical and knowledge capital and debt issues in the base period ($t=0$), given the current values of the exogenous variables. As the base period changes, and the new values of the exogenous variables are observed, the firm revises its previous plans. Hence only at the base periods are the plans actually carried out.

In order to carry out the maximization of the present

value of equity, it is necessary to more fully characterize the tax environment confronting the firm. In calculating the taxable income the firm is permitted depreciation deductions on one unit of the i^{th} capital stock of age t (at the original price) equal to $D_i(t)$, $i = p, r$. It is also true that the unit of the stock must be completely depreciated as $\int_0^{\infty} D_i(t) dt = 1$

The depreciation deductions at time t on all units of the i^{th} capital stock is $\int_0^{\infty} p_i(t-\tau) I_i(t-\tau) (1-v_i(t-\tau)) D_i(\tau) d\tau$, $i = p, r$ where $p_i(t) I_i(t)$ is the capital expenditure on i in period t and $D_i(0)$ is the depreciation deductions on a unit of capital installed at time t . The term $v_i(t)$ is the investment tax credit on the i^{th} stock in period t , and it reduces the base on which the depreciation deductions are calculated. Therefore the tax reduction from depreciation in period t is the corporate tax rate (defined as $u_c(t)$) multiplied by the depreciation deductions.

Suppose there is also an incremental investment tax allowance of $\gamma_i(t) \int_0^{\infty} \mu_i(\tau) p_i(t-\tau) I_i(t-\tau) d\tau$, $i = p, r$, where $\mu_i(0) = 1$,

$\mu_i(\tau) < 0$ for $\tau > 0$ and

$$\gamma_i(t) = \begin{cases} a_i(t) > 0 & \text{if } \int_0^{\infty} \mu_i(\tau) p_i(t-\tau) I_i(t-\tau) d\tau > 0, \\ 0 & \text{otherwise} \end{cases}$$

Hence if current investment expenditures exceed an average of past expenditures then the firm receives a tax allowance in period t of a_i on the i^{th} capital stock.

Using the previous results on tax reductions due to depreciation and the incremental tax allowances, the tax liability for

the firm in any period of time is

$$(6.6) \quad T_c = u_c [p^T Y - wL - r_b B] - \sum_{i=p}^r [u_c \int_0^{\infty} p_i(t-\tau) I_i(t-\tau) (1-v_i(t-\tau)) D_i(\tau) d\tau + u_c \gamma_i \int_0^{\infty} \mu_i(\tau) p_i(t-\tau) I_i(t-\tau) d\tau + v_i p_i I_i].$$

The base of the corporate income tax rate is the net revenues, which are revenues in excess of labour and debt interest payments. In addition, the taxes are reduced by the depreciation deductions, the incremental investment tax allowances and the investment tax credit.

The present value of the tax liability can be written in two parts, one part which depends on current decisions, and the other which is the result of past corporate plans. Before we write this expression, we introduce the specific tax policy that there is no incremental investment tax allowance for plant and equipment expenditures (i.e., $\gamma_p(t) = 0$ for all t), and research and development expenditures are deducted from income in the period they are incurred (i.e., $D_r(0) = 1$ and $D_r(t) = 0$ for all $t \neq 0$). Moreover, the investment tax credit is the same for both types of expenditure (i.e., $v_p = v_r = v$). Now the present value of the tax liability is,

$$\begin{aligned}
 (6.7) \quad \int_0^{\infty} e^{-\rho t} T_C(t) dt &= \int_0^{\infty} e^{-\rho t} [u_C(p^T Y - wL - r_b B - (1-v)p_r I_r) \\
 &\quad - v \sum_{i=p}^r p_i I_i - \int_0^{\infty} e^{-\rho \tau} [u_C(t+\tau) p_p(t) I_p(t) (1-v(t)) \vartheta_p(\tau) + u_C(t \\
 &\quad + \tau) \gamma_r(t+\tau) \mu_r(\tau) p_r(t) I_r(t)] d\tau - M(t) - N(t)] dt
 \end{aligned}$$

where $M(t) = u_C \int_0^{\infty} p_p(t-\tau) I_p(t-\tau) (1-v(t-\tau)) \vartheta_p(\tau) d\tau$ is the tax reduction based on depreciation deductions from past P&E expenditures, and $N(t) = u_C \gamma_r(t) \int_0^{\infty} \mu_r(\tau) p_r(t-\tau) I_r(t-\tau) d\tau$ is the incremental tax allowance on past R&D expenditures.

Using equation (6.7), the definition of Γ (from equation (6.3)) and assuming static expectations on the tax rates (u_C, v, γ_r) , we can write the present value of corporate shares as

$$\begin{aligned}
 (6.8) \quad S(0) &= \int_0^{\infty} e^{-\rho t} [(1-u_C)(pF(L, K_p, K_r, I_p, I_r) - wL - r_b B) \\
 &\quad - p_p I_p (1-v-d_p) - p_r I_r ((1-u_C)(1-v) - d_r) + \dot{B} + M + N] dt,
 \end{aligned}$$

where $d_p = u_C(1-v) \int_0^{\infty} e^{-\rho \tau} \vartheta_p(\tau) d\tau$ is the present value of the tax reaction due to depreciation deductions, $d_r = u_C \gamma_r \int_0^{\infty} e^{-\rho \tau} \mu_r(\tau) d\tau$. It is important to realize that the firm's objective has been rearranged so that it is in terms of labour requirements, investment in both physical and knowledge capital, debt issues, and the legacy of the past (namely K_p, K_r, B, M , and N).

Up to this point we have discussed all the aspects of the model except the process of corporate debt issues. It is now

assumed that corporate debt is used to finance the accumulation of the physical and knowledge capital stocks. Indeed, let us suppose that some fraction of debt always goes to finance some proportion of each of the real capital stocks. Thus

$$(6.9) \quad \psi_p p_p \dot{K}_p = \theta B \quad 0 < \psi_p < 1$$

$$(6.10) \quad \psi_r p_r \dot{K}_r = (1-\theta)B \quad 0 < \psi_r < 1.$$

This means that a fraction of physical capital and some fraction of knowledge capital exhaust the uses of debt. However, it is possible for the real capital stocks to be financed through internal funds and new share issues, since both ψ_p and ψ_r are positive but less than unity. We can also write these equations in terms of the investment in P&E and R&D. From equations (6.9) and (6.10) and because of static expectations on the prices (p_p, p_r), we have

$$(6.11) \quad \psi_p p_p \dot{K}_p + \psi_r p_r \dot{K}_r = \dot{B}$$

This equation states that a fixed proportion of net investment in physical and knowledge capital is financed by new debt issues.

Substituting (6.9) - (6.11) into (6.8) and integrating by parts yields,

$$V(0) = \int_0^\infty e^{-\rho t} [p_y y_1 + p_z F(y_1, L, K_p, K_r, I_p, I_r)$$

$$- w_\ell L - w_q K_p - w_s K_r] dt,$$

where $V(0) = S(0) - \int_0^\infty e^{-\rho t} (M(t) + N(t)) dt$, $p_y = p_1(1-u_c)$, $p_z = p_2(1-u_c)$, $w_\ell = w(1-u_c)$ and $y_2 = F(y_1, L, K_p, K_r, I_p, I_r)$ is the transformation function (see equation (6.1)) in terms of inventive output, $w_q = p_p[(\rho + \delta_p)(1-v-d_p) + \psi_p(r_b(1-u_c) - \rho)]$ and $w_s = p_r[(\rho + \delta_r)((1-u_c)(1-v)-d_r) + \psi_r(r_b(1-u_c) - \rho)]$. The prices w_q, w_s are the post tax rental rates on P&E and R&D. The problem confronting the firm is to maximize $V(0)$ by selecting L, I_p and I_r given the equations depicting the accumulation of real capital (i.e., equation (6.2)) and the initial conditions on these stocks.

Before we proceed, it is instructive to decompose the rental rates on physical and knowledge capital, since the tax policy instruments operate through these variables. Consider the rental rate on P&E (w_q). If the firm is all equity financed ($\psi_p = 0$), there is no investment tax credit ($v = 0$) and the tax authorities allow only economic depreciation ($d_p = u_c \delta / (\rho + \delta)$), then the post tax rental rate is equal to $p_p(\rho + \delta_p(1-u_c))$. However, if the firm is all debt financed ($\psi_p = 1$) then the rental rate is $p_p(r_b + \delta)(1-u_c)$, and if the firm is both debt and equity financed ($0 < \psi_p < 1$), the rental rate is $p_p[(1-\psi_p)\rho + \psi_p r_b(1-u_c) + \delta(1-u_c)]$. The term $(1-\psi_p)\rho + \psi_p r_b(1-u_c)$ is defined as the cost of physical capital, and it is the traditional weighted average of the costs of debt and equity financing. The expression $\psi_p(r_b(1-u_c) - \rho)$ represents the modification to the rental rate for the partially debt-financed firm relative to the all equity-financing situation. Finally, the existence of both an investment tax credit and accelerated depreciation decrease the

the rental rate. Similar reasoning can be used to explain the nature of the post tax rental rate on R&D capital.

We assume the firm operates in the interest of the shareholders. This implies that the present value of the shareholders' net flow of funds is maximized. Assuming that the intertemporal sequence of non-inventive output is given, the problem can be written as

$$\begin{aligned} \max_{(L, I_p, I_r)} \int_0^{\infty} e^{-\rho t} [p_Y y_1 + p_Z F(y_1, L, K_p, K_r, I_p, I_r) \\ - w_L L - w_q K_p - w_s K_r] dt \end{aligned}$$

$$\text{s.t. } \dot{K}_i = I_i - \delta_i K_i, K_i(0) = K_i^C, \quad i = p, r.$$

There are two ways in which we can represent the optimality conditions for the value maximizing problem; the primal and the dual. We shall concentrate on the dual to this problem, because of the flexibility this approach permits for the estimation of the model. Define $J(K_p, K_r, p_Y, p_N, w_L, w_q, w_s, y_1)$ to be the maximized present value of the net flow of funds, and therefore (see Dreyfus [1965], Arrow and Kurz [1970], and Epstein [1981]),

$$\begin{aligned} (6.12) \quad \rho J = p_Z F(y_1, L^0, K_p, K_r, I_p^0, I_r^0) - w_L L^0 \\ - w_q K_p - w_s K_r + J_p (I_p^0 - \delta_p K_p) + J_r (I_r^0 - \delta_r K_r), \end{aligned}$$

where $\partial J / \partial K_i = J_i$, $i = p, r$, and the superscript 0 denotes the

maximizing quantities. The conditions determining the optimal quantities for L , I_p and I_r are found by differentiating (6.12) with respect to w_ℓ , w_q and w_s . Thus

$$(6.13) \quad L^O = -\rho J_\ell + J_{p\ell}(I_p^O - \delta_p K_p) + J_{r\ell}(I_r^O - \delta_r K_r)$$

$$(6.14) \quad \rho J_q = -K_p + J_{pq}(I_p^O - \delta_p K_p) + J_{rq}(I_r^O - \delta_r K_r)$$

$$(6.15) \quad \rho J_s = -K_r + J_{ps}(I_p^O - \delta_p K_p) + J_{rs}(I_r^O - \delta_r K_r),$$

where the subscripts ℓ , q and s on J denote derivatives with respect to w_ℓ , w_q and w_s respectively.

Solving equations (6.12) - (6.15) yields the equations for physical and knowledge capital inputs, the labour input and the inventive output. We find that,

$$L^O = -\rho J_\ell + J_{k\ell}^T \dot{K}^O$$

$$(6.16) \quad \dot{K}^O = J_{k\omega}^{-1}(\rho J_\omega + K)$$

$$Y_2^O = \rho(J - w_\ell J_\ell - \omega_1^T J_\omega) - (J_k - w_\ell J_{k\ell} - \omega_1^T J_{k\omega}) \dot{K}^O,$$

where $J_{k\ell}^T = [J_{p\ell} \ J_{r\ell}]$, $J_{k\omega} = \begin{bmatrix} J_{pq} & J_{rq} \\ J_{ps} & J_{rs} \end{bmatrix}$, $J_\omega^T = [J_q \ J_s]$,

$$J_k^T = [J_p \ J_r], \ K^T = [K_p \ K_r], \ \omega_1^T = [w_q \ w_s], \ \dot{K}^O = \begin{bmatrix} I_p^O - \delta_p K_p \\ I_r^O - \delta_r K_r \end{bmatrix},$$

and p_z is normalized to unity. Equation set (6.16) is the model which is to be estimated. Notice that the model is a recursive system. The investment equations ($\dot{K}^O$) are a system of two

equations in two unknowns. The solution to the investment equations is then substituted into the labour requirements equation (L^0). Next, all three questions are substituted into the inventive output equation (y_2^0).

6.2 Specification and Estimation

In order to estimate equation set (6.16), a functional form for the maximized present value of the net flow of funds must be specified and an error structure imposed. We hypothesize the following functional form (see Epstein and Denny [1983] for a simpler version).

$$\begin{aligned}
 (6.17) \quad J(K_p, K_r, w_\ell, w_q, w_s, y_1) = & [\omega_1^T \ \omega_2^T] B_{ww} \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix} y_1 / 2 \\
 & + [\omega_1^T A_{\omega k}^{-1} + a_k^T + \omega_\ell a_\ell^T] K \\
 & + [\omega_1^T A_{\omega k}^{-1} h + \omega_\ell h_3 + h_0] / \rho,
 \end{aligned}$$

for where $\omega_1^T = [w_q \ w_s]$, $\omega_2^T = [w_\ell \ 1]$, B_{ww} is a positive definite symmetric 4×4 matrix of parameters, $A_{\omega k}^{-1}$ is the inverse of a 2×2 matrix of parameters such that $\rho I_2 + A_{\omega k}$ must be stable (I_2 is the 2×2 identity matrix), a_k^T , a_ℓ^T and h are 2 dimensional vectors of parameters, h_3 and h_0 are scalar parameters.

The corresponding set of investment demand, labour demand and inventive-output supply equations implied by (6.17) can be derived by noting that,

$$\rho J_{\omega} = \rho(B_{11}\omega_1 + B_{22}\omega_2)y_1 + \rho A_{\omega k}^{-1}K + A_{\omega k}^{-1}h$$

$$J_{k\omega} = A_{\omega k}^{-1}$$

$$\rho J_{\ell} = \rho y_1 [\omega_1^T \ \omega_2^T] b_{\ell} + h_3 + \rho a_{\ell}^T K$$

$$J_{k\ell} = a_{\ell}$$

where B_{11} is the submatrix of $B_{\omega\omega}$ which contains the first two rows and columns, B_{22} is the submatrix which contains the first two rows and last two columns of $B_{\omega\omega}$, b_{ℓ} is the third column of $B_{\omega\omega}$. Using these expressions and substituting into equation system (6.16) yields,

$$\begin{aligned} \dot{K}^O &= \rho A_{\omega k} (B_{11}\omega_1 + B_{22}\omega_2)y_1 + h + (\rho I_2 + A_{\omega k})K \\ (6.18) \quad L^O &= -\rho [\omega_1^T \ 1] b_{\ell} y_1 - h_3 - \rho a_{\ell}^T K + a_{\ell}^T \dot{K}^O \\ y_2^O &= -\rho \omega^T B_{\omega\omega} \omega y_1 / 2 + \rho b_o y_1 / 2 + h_o + \rho a_k^T K - a_k^T \dot{K}^O, \end{aligned}$$

where $\omega^T = [\omega_q \ \omega_s \ \omega_{\ell}]$, b_o is the last element in $B_{\omega\omega}$, and $B_{\omega\omega}$ are the first three rows and columns of $B_{\omega\omega}$.

The equation system (6.18) are the four equations to be estimated. They are our preferred specification. Notice that the investment and labour demand equations are linear in the factor prices and the capital stocks, while the inventive-output supply equation is linear in the capital stocks but nonlinear in the factor prices. In addition the investment equations are of the flexible accelerator since we can write,

$$\dot{K}^O = M(K - K^S)$$

where $M = (\rho I_2 + A_{\omega k})$, and $K^S = -(\rho I_2 + A_{\omega k})^{-1}(\rho A_{\omega k}(B_{11}\omega_1 + B_{22}\omega_2)y_1 + h)$. The matrix M is the adjustment matrix and the vector K^S represents the long-run magnitudes of the physical and knowledge capital stocks. An advantage of the dual approach to the dynamic problem is that the adjustment matrix is expressed in terms of the parameters of the value function, J . This implies that the technology can be quite flexible in terms of allowing interaction between the capital stocks and the rates of investment. Solving the primal problem usually necessitates an assumption that the adjustment matrix is diagonal. A diagonal adjustment matrix implies that the elasticity of substitution between the capital stocks is zero, and the marginal adjustment costs of a particular form of capital depends only on that type of capital. These are strong assumptions which have not been imposed in the present context.

The system (namely set (6.18)) that is to be estimated is nonlinear in the parameters, with parameter restrictions within and across equations. As we have mentioned, the system is linear in the variables and block recursive in the sense that the two net investment equations are simultaneous. The solutions to these two equations then feed into the labour demand and inventive output supply equations. By taking a discrete approximation to (6.18), where $\dot{K}(t) \approx K(t) - K(t-1)$ and $K \approx K(t-1)$, and by appending error terms ($u(t)$) to each of the equations, which are assumed to be jointly normally distributed with zero mean ($E(u) = 0$) and with positive definite symmetric covariance matrix ($E(uu^T) = \Omega \otimes I_T = \Phi$, where Ω is a 4×4 matrix), we can use the nonlinear maximum likelihood estimator.

The estimated equations can be written out as

$$\begin{aligned}
 (6.19) \quad K_p^O(t)/Y_1 = & (a_{11}b_{11} + a_{12}b_{12})\rho(w_p + \psi_p w_e) \\
 & + (a_{11}b_{12} + a_{12}b_{22})\rho(w_r + \psi_r w_d) \\
 & + (a_{11}b_{13} + a_{12}b_{23})\rho w_\ell \\
 & + (a_{11}b_1 + a_{12}b_2)\rho + h_1/Y_1 \\
 & + (1 + \rho + a_{11})K_p(t-1)/Y_1 + a_{12}K_r(t-1)/Y_1 + u_p(t).
 \end{aligned}$$

$$\begin{aligned}
 (6.20) \quad K_r^O(t)/Y_1 = & (a_{21}b_{11} + a_{22}b_{12})\rho(w_p + \psi_p w_e) \\
 & + (a_{21}b_{12} + a_{22}b_{22})\rho(w_r + \psi_r w_d) \\
 & + (a_{21}b_{13} + a_{22}b_{23})w_\ell \\
 & + (a_{21}b_1 + a_{22}b_2)\rho + h_2/Y_1 \\
 & + a_{21}K_p(t-1)/Y_1 + (1 + \rho + a_{22})K_r(t-1)/Y_1 + u_r(t).
 \end{aligned}$$

$$\begin{aligned}
 (6.21) \quad L^O(t)/Y_1 = & -b_{13}\rho(w_p + \psi_p w_e) - b_{23}\rho(w_r + \psi_r w_d) \\
 & - b_{33}\rho w_\ell - b_3\rho - h_3/Y_1 \\
 & + a_3 K_p^O(t)/Y_1 + a_4 K_r^O(t)/Y_1 \\
 & - (1+\rho)a_3 K_p(t-1)/Y_1 - (1+\rho)a_4 K_r(t-1)/Y_1 + u_\ell(t)
 \end{aligned}$$

$$\begin{aligned}
 (6.22) \quad Y_2^O(t)/Y_1 = & b_0\rho/2 + h_0/Y_1 - b_{11}\rho(w_p + \psi_p w_e)^2/2 \\
 & - b_{12}\rho(w_p + \psi_p w_e)(w_r + \psi_r w_d) - b_{22}\rho(w_r + \psi_r w_e)^2/2 \\
 & - b_{13}\rho(w_p + \psi_p w_e)w_\ell - b_{23}\rho(w_r + \psi_r w_d)w_\ell - b_{33}\rho w_\ell^2/2 \\
 & - a_1 K_p^O(t)/Y_1 - a_2 K_r^O(t)/Y_1 + (1+\rho)a_1 K_p(t-1)/Y_1 \\
 & + (1+\rho)a_2 K_r(t-1)/Y_1 + v_z(t),
 \end{aligned}$$

where $w_p = p_p(\rho + \delta_p)(1-v-d_p)$, $w_e = p_p(r_b(1-u_c) - \rho)$,

$w_r = p_r(\rho + \delta_r)((1-u_c)(1-v)-d_r)$, $w_d = p_r(r_b(1-u_c) - \rho)$. There are 24 parameters to be estimated from 135 observations.

The estimates are presented in Table 6.1. We can observe that most of the estimates are significant. The system of equations converged with a criteria of .01, and we experimented with alternative initial values which yielded essentially the same results. The condition that B_{ww} is a positive definite matrix

Table 6.1
Estimation Results

<u>Parameter</u>	<u>Estimate</u>	<u>t-Statistic</u>
b_0	805.381	2.353
h_0	13.857	2.573
h_1	7.141	4.722
h_2	6.824	5.297
h_3	-125.380	-3.938
a_1	51.217	4.459
a_2	59.941	3.719
a_3	-.659	-2.620
a_4	-1.309	-1.817
b_3	-5.215	-9.006
b_{33}	.022	4.440
b_{13}	.015	2.172
b_{23}	.004	1.801
b_{22}	.021	4.933
b_{12}	.003	8.632
b_{11}	.061	2.175
b_1	-7.518	-4.279
b_2	-1.885	-3.108
a_{11}	-.331	-5.378
a_{12}	.049	6.030
a_{22}	-.262	-3.085
a_{21}	.009	4.225
ψ_p	.471	2.687
ψ_r	.092	4.350

Log Likelihood Function 334.582

is satisfied. This can be seen from the values of the b_{ij} $i, j = 1, 2, 3$ and b_i $i = 1, 2$ coefficients in Table 6.1. This condition was not imposed on the data. In addition, the condition that $\rho I_2 + A_{\omega k}$ be a stable matrix (see the a_{ij} $i, j = 1, 2$ coefficients) was imposed on the data as in Lau [1978]. We can observe from equation (6.19) with $1 + \rho + a_{11} > 0$ and $a_{12} > 0$, that increases in the existing stocks of physical and R&D capital increase the demand for the physical capital input. The same conclusion holds regarding the demand for R&D capital as $1 + \rho + a_{22} > 0$ and $a_{21} > 0$ (see equation (6.20)). Turning to the labour demand equation (6.21), we find the expected result that $a_3 < 0$, $a_4 < 0$. Given the level of non-inventive output, as the demand for physical or R&D capital increase, labour requirements must fall.

The patent equation (6.22) illustrates with $a_1 > 0$, $a_2 > 0$, that firms with larger existing stocks of physical and R&D capital will have a larger number of patents. Moreover, if we multiply both sides of equation (6.22) by y_1 , and because $b_{ij} > 0$ $i, j = 1, 2, 3$, then (given the demands for the capital inputs) increases in non-inventive output decrease the number of patents. This is the expected relationship between the two outputs. It implies that for a given quantity of resources, there must be a trade-off between the two forms of output produced by the firm.

We are able to determine from Table 6.1 the financing composition of physical and R&D capital. Recall that the coefficients ψ_p and ψ_r signify the proportion of debt financing of physical and

R&D capital respectively. Our estimation reveals that almost 50% of physical capital accumulation is debt financed, while only about 10% of R&D capital accumulation is funded through corporate bonds. Conversely, equity funds 50%, and 90% of physical and R&D capital accumulation respectively. Therefore, based on a dynamic optimizing model of firm behaviour, we have established that R&D capital is significantly more equity financed compared to physical capital.

The adjustment process of the capital stocks can also be discerned from the a_{ij} $i, j = 1, 2$ coefficients in Table 6.1. The estimate of $-(a_{11} + \rho)$, where the mean value of ρ (the shareholders' flow of funds discount rate) is .087, illustrates the proportion of physical capital that adjusts within a single year. This adjustment occurs given the stock of R&D capital. Thus within a single year $(.331 - .087)$.244 or 24.4% of the adjustment of physical capital occurs (given the stock of R&D capital). In a similar fashion $-(a_{22} + \rho)$ signifies the adjustment of R&D capital which occurs in a year. Given the stock of physical capital $(.262 - .087)$.175 or 17.5% of the adjustment of R&D capital takes place in the year.

The adjustment process in the present context is more complex due to the presence of the interaction terms between the capital inputs. The coefficient a_{12} and a_{21} denote the interaction terms between the capital inputs. An increase in the stock of R&D capital causes (a_{12}) .049 or 4.9% of the adjustment of physical capital to occur in a single year. Thus the total adjustment of physical capital in one year is $(.244 + .049)$.293 or 29.3%. This

implies that it takes almost 3.5 years for the physical capital stock to adjust to its long-run level. Similarly, an increase in the stock of physical capital generates (a_{21}) .009 or .9% of the adjustment of R&D capital to occur in one year. Thus $(.175 + .009)$.184 or 18.4% of the total adjustment on R&D capital takes place in a year. This means that R&D capital takes about 5.5 years to adjust to its long-run level. Therefore, R&D capital takes longer to adjust compared to physical capital. In addition, increases in any one capital stock decreases the adjustment period of the other. There is a form of complementarity between the capital stocks during the adjustment path.

7. Factor Prices, Non-Incentive Output and Input Demands

The objective of this chapter is to derive the effects of increases in the input prices on the demands for physical capital, R&D capital and labour. The reason we undertake this set of experiments is because the tax incentives towards physical and R&D investment have the effect of altering the unit cost or price associated with the capital inputs. For example, if 10% of the annual expenditure on equipment and structures can be deducted from a firm's tax liability, then the after tax cost of these expenditures decreases by the 10%. This implies that the price the firm pays for the physical capital has decreased. The price falls below the market price because of the existence of the tax incentives.

In order to arrive at the effect of a change in a tax incentive on the array of factor demands a two step procedure is involved. First, because these incentives operate through the factor prices, we must derive the impact on factor demands that changes in input prices generate. Second, we have to find the effects of changes in the tax incentives on the input prices. The combination of these two sets of results point out the tax incentive impacts on the demand for the factors of production.

7.1 Factor Price Effects

The purpose of this chapter is to undertake the first step of the two stage procedure. From Table 7.1, we find the formulas for the long-run effects (or elasticities) of the inputs with respect to each of the factor prices. In order to derive these formulas set $K_i(t) = K_i(t-1)$ $i = p, r$ in equations (6.19), (6.20)

Table 7.1

Formulas for the Long-Run Price Elasticities of Factor Demands With Variable Patent

Frequency

actor Price

Factor Demands

	K_P^i (physical capital)	K_R^i (knowledge capital)	L^i (labour)
1 (physical capital)	$e_{pq}^i = - \frac{w_{pq}}{K_P^i} [(a_{11}b_{11} + a_{12}b_{12})$ $(a_{22} + \rho) - (a_{21}b_{11} + a_{22}b_{12})a_{12}]$	$e_{rq}^i = - \frac{w_{rq}}{K_R^i} [(a_{21}b_{11} + a_{22}b_{12})$ $(a_{11} + \rho) - (a_{11}b_{11} + a_{12}b_{12})a_{21}]$	$e_{iq}^i = - \frac{w_{iq}}{L^i} b_{13} - a_3 \rho \frac{K_R^i}{L^i} e_{pq}^i$ $- a_4 \rho \frac{K_R^i}{L^i} e_{rq}^i$
2 (knowledge capital)	$e_{ps}^i = - \frac{w_{ps}}{K_P^i} [(a_{11}b_{12} + a_{12}b_{22})$ $(a_{22} + \rho) - (a_{21}b_{12} + a_{22}b_{22})a_{12}]$	$e_{rs}^i = - \frac{w_{rs}}{K_R^i} [(a_{21}b_{12} + a_{22}b_{22})$ $(a_{11} + \rho) - (a_{11}b_{12} + a_{12}b_{22})a_{21}]$	$e_{is}^i = - \frac{w_{is}}{L^i} b_{23} - a_3 \rho \frac{K_R^i}{L^i} e_{ps}^i$ $- a_4 \rho \frac{K_R^i}{L^i} e_{rs}^i$
3 (labour)	$e_{pi}^i = - \frac{w_{pi}}{K_P^i} [(a_{11}b_{13})$ $+ a_{12}b_{23}] (a_{22} + \rho)$ $- (a_{21}b_{13} + a_{22}b_{23})a_{12}]$	$e_{ri}^i = - \frac{w_{ri}}{K_R^i} [(a_{21}b_{13})$ $+ a_{22}b_{23}] (a_{11} + \rho)$ $- (a_{11}b_{13} + a_{12}b_{23})a_{21}]$	$e_{ii}^i = - \frac{w_{ii}}{L^i} b_{33} - a_3 \rho \frac{K_R^i}{L^i} e_{pi}^i$ $- a_4 \rho \frac{K_R^i}{L^i} e_{ri}^i$

and (6.21). The long-run is defined for the stationary magnitudes of the capital stocks. The magnitudes are presented in Table 7.2. We find that an increase in a factor price decreases the demand to which it is associated. These results are seen by the negative numbers along the diagonal of Table 7.2. These are referred to as the own elasticities (or effects). The own effects are inelastic (i.e., less than unity in absolute value), with labour requirements the most responsive relative to the capital inputs. Both types of capital exhibit highly inelastic effects, with R&D capital slightly more inelastic than physical capital.

Turning to the off-diagonal elements in Table 7.2, we refer to these effects as the cross elasticities. The first result we can observe is that an increase in any factor price decreases the demands for all inputs. Recall that inventive output is not held fixed in this model. There is no need for compensating variations in the input requirements in response to a price change. The second result is that labour demand is more responsive to an increase in the rental rate on physical capital relative to the impact on demand for R&D capital (see the first row of Table 7.2). This result carries over to changes in the rental on R&D capital. Labour requirements decrease relatively more from increases in the price of the R&D capital inputs compared to decreases in the demand for physical capital. Lastly, from the last row of Table 7.2, we find that a percentage increase in the wage rate elicits virtually the same percentage decrease in both capital inputs. Firms reduce their capital inputs in equal proportions as the unit labour costs increase.

Table 7.2
Long-Run Price Elasticities of Factor Demands With Variable
Factor Frequency

	Factor Demand		
	K_P^L	K_R^L	L^L
w_q	-.2882	-.0677	-.1465
w_s	-.0124	-.2085	-.0306
w_l	-.3516	-.3266	-.8306

The formulas for the short-run price effects are found in Table 7.3. These formulas are derived directly from equations (6.19), (6.20) and (6.21). The magnitudes are found in Table 7.4. A number of results emerge. First, the own effects are negative, as in the long-run. In addition, as expected the short-run own elasticities are smaller, in absolute value, than the long-run effects. The relative responsiveness of the three inputs is preserved, as labour exhibits the most elastic effect, followed by physical and R&D capital.

The off-diagonal or cross effects also illuminate some interesting features. First, an increase in the rental rate on physical capital causes the demand for R&D capital and labour to decrease, with labour the more responsive of the two factors. These effects are similar to the long-run. However, when the rental rate on R&D capital increases, the short-run results are quite different from the long-run elasticities. In response to the rental increase, there is no change in the demand for physical capital and labour requirements increase. In the long-run both demands actually decrease. Thus, in the short-run, there is very little interaction between the capital inputs as the R&D capital rental rate increases. Moreover, in this case, firms substitute labour for 'know-how'. Finally, an increase in the wage rate causes all input demands to decrease. These effects are the largest, in absolute value, and both capital inputs respond in a similar fashion. These effects are similar to the long-run. The results point out that factor prices significantly (in a statistical sense) but inelastically (in terms of magnitude) affect the demand for R&D

Table 7.3

Formulas for the Short-Run Price Elasticities of Factor Demands
With Variable Patent Frequency

Factor Price	Factor Demands		
	K_p^s (physical capital)	K_r^s (knowledge capital)	L^s (labour)
w_q (physical capital)	$e_{pq}^s = \frac{w_{qpy}}{K_p^s} (a_{11}b_{11} + a_{12}b_{12})$	$e_{rq}^s = \frac{w_{qpy}}{K_r^s} (a_{12}b_{11} + a_{22}b_{12})$	$e_{lq}^s = -\frac{w_{qpy}}{L^s} b_{13} + a_3 \frac{K_p^s}{L^s} e_{pq}^s$
w_s (knowledge capital)	$e_{ps}^s = \frac{w_{spy}}{K_p^s} (a_{11}b_{12} + a_{21}b_{22})$	$e_{rs}^s = \frac{w_{spy}}{K_r^s} (a_{21}b_{12} + a_{22}b_{22})$	$e_{ls}^s = -\frac{w_{spy}}{L^s} b_{23} + a_3 \frac{K_p^s}{L^s} e_{ps}^s$
w_l (labour)	$e_{pl}^s = \frac{w_{lpy}}{K_p^s} (a_{11}b_{13} + a_{12}b_{23})$	$e_{rl}^s = \frac{w_{lpy}}{K_r^s} (a_{21}b_{13} + a_{22}b_{23})$	$e_{ll}^s = -\frac{w_{lpy}}{L^s} b_{33} + a_3 \frac{K_p^s}{L^s} e_{pl}^s$

Table 7.4
Short-Run Price Elasticities of Factor Demands with Variable
Patent Frequency

	Factor Demand		
	K_p^s	K_r^s	L^s
w_q	-.0754	-.0034	-.0118
w_s	0	-.0389	.0148
w_l	-.0882	-.0501	-.6591

capital. We also see that there are interactions between the factors of production and that important differences emerge between the short and long-runs.

7.2 Non-Inventive Output Effects

In this section we discuss the effect that changes in non-inventive output (in the short and long-run) exert on the demands for the capital inputs and labour. The formulas for the long and short-runs are given in Table 7.5, and the magnitudes are presented in Table 7.6.

From Table 7.6, we can observe that the long-run non-inventive output elasticities are larger than the short-run. The presence of adjustment costs associated with the capital inputs cause the firm to meet increases in non-inventive output by increases in labour demand, which are relatively larger than those for the capital inputs. Notice that, in the long-run, after the adjustment costs have been absorbed, all the inputs increase by the same percentage, as non-inventive output rises.

The last issue concerns the relative impact of factor prices and non-inventive output on the input requirements. Comparing Tables 7.2, 7.4 and 7.6, we can clearly see that for the capital inputs, in both the short and long-runs, the output effects dominate the price effects. Indeed, for physical capital the short-run output elasticity dominates all the long-run elasticities associated with this input. For R&D capital and labour demands, the same conclusion holds with respect to changes in the rental rates, only the long-run wage rate elasticity exerts a marginally greater impact than the short-run output effects. These magnitudes imply

Table 7.5

Formulas for the Non-Inventive Output Elasticities of Factor Demands With
Variable Patent Frequency

	Factor Demand		
	K_P	K_R	L
Long-Run	$e_{py}^L = 1 + h_1(a_{22} + \rho)/K_P^L H$ $- h_2 a_{12}/K_P^L H$	$e_{ry}^L = 1 + h_2(a_{11} + \rho)/K_R^L H$ $- h_2 a_{12}/K_R^L H$	$e_{ly}^L = 1 + h_3/L^L - a_3 \rho K_P^L$ $/L^L e_{py}^L - a_4 \rho K_R^L /L^L e_{ry}^L$ $+ a_3 \rho K_P^L /L^L$ $+ a_4 \rho K_R^L /L^L$
Short-Run	$e_{py}^S = 1 - h_1/K_P^S$ $- (1 + \rho + a_{11})K_P^S(-1)$ $/K_P^S - a_{12}K_R^S(-1)/K_P^S$	$e_{ry}^S = 1 - h_2/K_R^S$ $- (1 + \rho + a_{22})K_R^S(-1)$ $/K_R^S - a_{21}K_P^S(-1)/K_R^S$	$e_{ly}^S = 1 + h_3/L^S + a_3 K_P^S /L^S e_{py}^S + a_4 K_R^S /L^S e_{ry}^S$ $- a_3 K_P^S /L^S - a_4 K_R^S /L^S$ $+ (1 + \rho) a_3 K_P^S(-1)/L^S$ $+ (1 + \rho) a_4 K_R^S(-1)/L^S$

Table 7.6
Non-Inventive Output Elasticities of Factor Demands With Variable
Patent Frequency

	Factor Demand		
	K_p	K_r	L
Long-Run	.9998	.9993	.9987
Short-Run	.4362	.2843	.5398

an important conclusion. Events and government policies which affect output will generate stronger impacts on the structure of production compared to changes in the tax incentives on physical and R&D investment.

8. Patents, Non-Inventive Output and Factor Prices

The purpose of this chapter is to analyse the determinants of patent frequency. In our model, the number of patents is a proxy for the quantity of inventive output. The supply of inventive output is the outcome of an intertemporal flow of funds maximization process. Consequently, factor and product prices, as well as product demand and technological characteristics influence the supply of inventive output.

8.1 Non-Inventive Output Elasticities

In this study the focus is on patents and R&D investment. Hence, in order to avoid the further complications of an analysis involving multiple outputs, we have assumed that non-inventive output is exogenous. This assumption permits us to obtain a patent equation in terms of prices and non-inventive output. In addition, because the capital inputs are fixed in the short-run due to the presence of adjustment costs, the existing stocks of physical and R&D capital at each point in time are determinants of patent frequency. From equation set (6.18) we can observe that factor prices, non-inventive output, the stocks and rates of accumulation of physical and R&D capital explain patents.

Generally patents have been explained in a somewhat ad hoc manner by R&D investment (or R&D expenditures) and output (or sales). From our optimizing framework, we find that factor prices, the stocks and accumulation of all types of capital must be included in the estimation. Moreover, the fact that the ad hoc equations have contained non-inventive output or sales as an

explanatory variable implies the assumption of the exogeneity of the latter variable holds (albeit implicitly).

In Table 8.1 we provide the formulas for the long and short-run non-inventive output elasticities of patent frequency. The long-run formulas have been derived by letting $K_i(t) = K_i(t-1)$ $i = p, r$ in equation (6.22). The firm is in long-run equilibrium so that the capital stocks are stationary. From Table 8.2 we find the magnitudes of these elasticities. In the short-run a 1% increase in non-inventive output causes the number of patents to increase by slightly over .64%. Notice there is a positive relationship between non-inventive output and patents. The reason for this arises from the fact that non-inventive output increases physical and R&D capital, which, in turn, increases the number of patents. This result is perfectly consistent with the estimated inverse relationship between the two outputs when all input requirements are given.

In the short-run, because of the presence of adjustment costs, the capital inputs respond in an inelastic fashion to increases in non-inventive output. This translates into an inelastic response by the firm with respect to the number of patents. However, as the adjustment costs are absorbed, the capital inputs become more responsive. This causes the non-inventive output elasticity of patents to increase to unity. In the long-run a 1% increase in non-inventive output leads to a 1% increase in the number of patents. From our estimation, we find that patents increase in proportion to the size of the firm (as represented by non-inventive output), in the long-run. We are not able to accept the hypothesis (either in the short or long-runs) that patents increase

Table 8.1

Formulas for the Output and Factor Price Elasticities of Patent Frequency

	y (Non-Inventive Output)	w_q (Factor Price of Physical Capital)	w_s (Factor Price of R&D Capital)	w_l (Factor Price of Labour)
Long-Run	$e_{zy}^L = [z^L - h_0 + a_1 \rho K_e^L L / p p y + a_2 \rho K_e^L L / r y - a_1 \rho K_p^L - a_2 \rho K_r^L] / z^L$	$e_{zq}^L = [-w_q \rho y (b_{11} w_q + b_{12} w_s + b_{13} w_l) + a_1 \rho K_e^L L / p p q + a_2 \rho K_r^L L / r q] / z^L$	$e_{zs}^L = [-w_s \rho y (b_{12} w_q + b_{22} w_s + b_{23} w_l) + a_1 \rho K_e^L L / p p s + a_2 \rho K_r^L L / r s] / z^L$	$e_{zl}^L = [-w_l \rho y (b_{13} w_q + b_{23} w_s + b_{33} w_l) + a_1 \rho K_e^L L / p p l + a_2 \rho K_r^L L / r l] / z^L$
Short-Run	$e_{zy}^S = [z^S - h_0 - a_1 (1+\rho) K_r^S (-1) - a_2 (1+\rho) K_r^S (-1) + a_1 K_p^S + a_2 K_r^S - a_1 K_e^S / p p y - a_2 K_e^S / r y] / z^S$	$e_{zq}^S = [-w_q \rho y (b_{11} w_q + b_{12} w_s + b_{13} w_l) - a_1 K_e^S / p p q - a_2 K_e^S / r q] / z^S$	$e_{zs}^S = [-w_s \rho y (b_{12} w_q + b_{22} w_s + b_{23} w_l) - a_1 K_e^S / p p s - a_2 K_e^S / r s] / z^S$	$e_{zl}^S = [-w_l \rho y (b_{13} w_q + b_{23} w_s + b_{33} w_l) - a_1 K_e^S / p p l - a_2 K_e^S / r l] / z^S$

Table 8.2

Non-Inventive Output and Factor Price Elasticities of Patent
Frequency

	y	w_q	w_s	w_l
Long-Run	1.0000	-.2826	-.0429	-1.1577
Short-Run	.6415	-.1699	-.0193	-1.0391

in a greater proportion relative to firm size.

8.2 Factor Price Elasticities

From Table 8.1, we can also find the formulas for the short and long-run factor price elasticities of patent frequency. These elasticities point out the proportional change in the number of patents for a proportional increase in the factor prices of physical capital, R&D capital and labour. The actual magnitudes are presented in Table 8.2. Recall that the number of patents is treated as a measure of inventive output. This implies that a change in any one factor price, which cause factor demands to decrease, must also cause the number of patents to decline.

In the short-run a 1% increase in the rental rate on physical capital leads to a decrease in the number of patents by .17%. Clearly, a highly inelastic effect. The most inelastic response emanates from the increase in the rental rate on R&D capital. A 1% increase in this latter rate only decreases the number of patents by .02%. Capital input price changes in the short-run generate very little response from the number of patents. Moreover, these results also obtain in the long-run. The long-run elasticities are approximately twice as large (in absolute value) as the short-run magnitudes, but the former are still highly inelastic.

The effects generated by increases in the wage rate are the largest (in absolute value) of the three factor prices. A 1% increase in the wage rate in the short-run causes the number of patents to decrease by the same percentage. In the long-run the effect is slightly elastic. Although the long-run result is more elastic than the short-run, the effects are not substantially different.

9. Tax Incentives, Factor Demands and Patent Frequency

The purpose of this chapter is to determine the effects of changes in the physical and R&D investment tax credits, and the R&D investment incremental tax allowance on the factors of production and patent frequency.

9.1 Physical Investment Tax Credit

The type of tax credit on physical investment is related to a rate (v_p) which is applied to annual expenditures on physical capital (namely structures and equipment). In general, the tax credit has been implemented in two ways. The first is when the tax liability of the firm is reduced by v_p of its annual expenditures. This credit does not reduce the depreciation base for tax purposes on physical capital. For example if the firm spends \$1 on physical capital, with a depreciation rate of 30% and a discount rate of 15%, the present value of depreciation deductions is \$.67. In the absence of any credit, and with a constant corporate income tax rate of u_c , the tax reduction is \$.67 u_c . Thus the post tax cost of investment is $\$(1 - .67u_c)$. With a constant tax credit of v_p the tax reduction is $\$(.67u_c + v_p)$ and so the post tax cost of the investment is $\$(1 - (.67u_c + v_p))$. With a corporate income tax of .46, and an investment tax credit of .1, the tax reduction on a \$1 expenditure is \$.41.

The second manner in which the credit has been implemented involves the reduction in the depreciation base of physical capital by the amount of the credit. Now with the present value of depreciation deductions of \$.67 the tax reduction on \$1 of

expenditures is $\$[u_c(.67 - v_p) + v_p]$ and the post tax cost of the physical investment is $\$1 - \$[u_c(.67 - v_p) + v_p] = (1 - .67u_c) - v_p(1 - u_c)$. Using $u_c = .46$, and $v_p = .1$ then the tax reduction is \$.36, which is \$.05 [or (.46)] smaller than the first case. The differences in the two situations relates to the base over which the tax credit is applied.

The physical investment tax credit alters the post tax unit cost of the physical capital input. This unit cost or the rental rate is $w_q = p_p[(\rho + \delta_p)(1 - v_p - d_p) + \psi_p(r_b(1 - u_c) - \rho)]$ (see the discussion on page 53). A change in the tax credit can affect the rental rate in two ways. First, the cost of current physical investment expenditures is lowered by the credit. Second, because the credit may decrease the depreciation base, future depreciation deductions are lower due to the credit. Hence the credit decreases the present tax liability and increases future tax liabilities.

An increase in the tax credit causes the rental rate to change by $-[p_p(\rho + \delta_p)(1 - \partial d_p / \partial v_p)]$. Clearly the rental decreases by $-p_p(\rho + \delta_p)$ due to the decrease in the present tax liability and the rental increases by $p_p(\rho + \delta_p) \partial d_p / \partial v_p$ due to the increase in future tax liabilities. The present decrease outweighs the future increase because only a fraction of the cost (that based on the depreciation charge) is raised, and the future is discounted.

In order to determine the net effect on the rental rate, we must determine the effect of a change in the credit (v_p) on the present value of the tax reduction due to depreciation deductions (d_p). We know that $d_p = u_c(1 - v_p) \int_0^\infty e^{-\rho\tau} \dot{v}_p(\tau) d\tau$. Let $z = \int_0^\infty e^{-\rho\tau} \dot{v}_p(\tau) d\tau$. Thus an increase of 1% in the physical investment

tax credit decreases the rental rate by $-[p_p(\rho + \delta_p)(1-u_c z)v_p/w_q]\%$. Notice that if the investment tax credit did not decrease the depreciation base then a 1% increase in the tax credit would decrease the rental rate by $-p_p(\rho + \delta_p)v_p/w_q\%$.

The short and long-run factor demand and inventive output supply effects (or elasticities) with respect to increases in the physical investment tax credit rate are presented in Table 9.1. A 1% increase in the rate decreases the rental on physical capital by $-.181\%$. In other words, the present value of the unit cost reduction from a 1% increase in the credit is $.181\%$. The top rows are derived by applying this present value to the first row of Table 7.2 and 7.4 and the second columns of Table 8.2.

A number of results emerge from these rows. First, an increase in the tax credit rate increases the demand for all the factors of production and the supply of the number of patents. The pattern of Table 9.1 follows the relevant parts of Tables 7.2 7.4 and 8.2. Second, the results are more inelastic, because an increase in the tax credit rate does not reduce the rental by the same proportion. Notice that a 1% increase in the tax credit rate increases the demand for R&D capital by $.012\%$ in the long-run and $.001\%$ in the short-run. However, the effect on patent frequency is stronger. In the long-run the effect is over four-fold greater and in the short-run the effect is over thirty times greater. The reason is that patent frequency is not only a function of R&D capital, but it is also a function of the physical capital and labour inputs. Increases in the demands for these other factors, generate further increases in the supply of patents.

Table 9.1

Long and Short-Run Physical Investment Tax Credit Elasticities

	Factor Demand			Patent Frequency
	K_p	K_r	L	
Decrease in Depreciation Base				
Long-Run	.052	.012	.027	.051
Short-Run	.014	.001	.002	.031
No Decrease in Depreciation Base				
Long-Run	.076	.018	.040	.075
Short-Run	.021	.002	.003	.045

If we introduce the policy change that the tax credit does not reduce the base on which depreciation deductions are calculated then recall the decrease in the rental rate is $-p_p(\rho + \delta_p)v_p/w_q\%$. The term $\partial d_p/\partial v_p = 0$ since the present value of the tax reduction due to depreciation deductions (d_p) is independent of the credit rate. In this case, the decrease in the rental rate is $-.265\%$. The results are given by the last two rows of Table 9.1. We can observe that the elasticities are uniformly larger, generally 50% greater, than the case when the credit decreases the depreciation base. Thus in a relative sense there is a significant increase in the degree to which the physical investment tax credit influences input requirements and patent frequency.

9.2 R&D Investment Tax Credit

The general analysis pertaining to the physical investment tax credit carries over to this section. We begin the discussion with the rental rate on R&D capital, because a change in the tax credit affects the price the firm pays per unit of the R&D capital input. The rental rate is $w_s = p_r[(\rho + \delta_r)((1-u_c)(1-v_r) - d_r) + \psi_r(r_b(1-u_c) - \rho)]$ (see the discussion on page 53). Thus a 1% increase in the R&D investment tax credit decreases the rental rate by $-[p_r(\rho + \delta_r)(1-u_c)v_r/w_s]\%$.

The short and long-run factor demand and inventive output supply elasticities are presented in the first two rows of Table 9.2. We derived these rows by multiplying the percentage decrease in the rental rate on R&D investment tax credit rate to the second row of Tables 7.2 and 7.4 and the third column of

Table 9.2

Long and Short-Run R&D Investment Tax Credit Elasticities

	Factor Demand			Patent Frequency
	K_p	K_r	L	
Effective Tax Credit (.05)				
Long-Run	.001	.018	.003	.024
Short-Run	0	.003	-.001	.014
Statutory Tax Credit (.1)				
Long-Run	.003	.044	.007	.060
Short-Run	0	.008	-.003	.036

Table 8.2. The decrease in the rental rate is 0.084% which is substantially less than the percentage decline in the physical capital rental (-.181). The physical investment tax credit decreases the rental rate on physical capital by more than double the corresponding decrease of the R&D capital rental generated by the tax credit on R&D investment. The reason for this difference stems from the fact that R&D investment tax credits are severely unutilized. The underutilization diminishes the impact on the factor price or unit costs.

The top rows of Table 9.2 illustrate that, in the long-run, the R&D investment tax credit generates positive but highly inelastic effects on all inputs and patent frequency. In the short-run, the effects are more inelastic. Moreover, we find that an increase in the credit does not affect physical capital and it reduces labour requirements by a very small percentage.

The bottom half of Table 9.2 is derived by assuming that the statutory tax credit rate is in effect. In this context the rental rate decreases by -.213%. Thus the percentage decline in the rental rate when all the credits are utilized is 250% greater than the decline under the actual effective rate. An important implication is that closing the gap between the effective and statutory rates cause a significant decline in the unit costs of production. The consequence of the larger percentage decrease in the rental rate is to increase (in absolute value) the elasticities. The figures at the bottom of Table 9.2 are larger (in absolute value) than those at the top. Notice, not only do the percentage increases become larger (say for R&D capital and patent frequency) but the percentage decrease in labour requirements

becomes more negative.

We can compare the top part of Table 9.1 with Table 9.2. First, as expected, increases in the physical investment credit relative to the R&D investment credit lead to greater increases in the demand for physical capital. Second, the former credit is more effective in stimulating labour requirements in both the short and long-runs. Third, there is not a substantial difference in the expansion of R&D capital between the types of credits. This is due to the underutilization of the R&D investment tax credit. We find that the physical investment tax credit is about as effective in stimulating the demand for R&D capital. The comparisons on physical capital and labour carry over to the bottom half of Table 9.2. However, we can see that when all the R&D investment tax credits are utilized, increases in this credit generate significantly more demand for R&D capital relative to the physical investment tax credit.

Patent frequency is also affected differentially by the two types of credits. In the situation when the R&D investment tax credits are underutilized, the impact on patent frequency is half that generated by increases in the physical investment tax credit. This result holds in the short and long-runs. Once the problem of underutilization has been rectified, both types of tax credits cause approximately the same effect on patent frequency. Indeed, the edge belongs to the R&D investment tax credit.

If we assume that Canadian policy changes, such that the tax credit does not reduce the tax deductible R&D expenditures, then we arrive at new elasticities. These are presented in Table 9.3. The top and bottom halves of Table 9.3 are derived from the fact

Table 9.3

Long and Short-Run R&D Investment Tax Credits Elasticities
Without Reduction in R&D Expense

	Factor Demand			Patent Frequency
	K_p	K_r	L	
Effective Tax Credit (.05)				
Long-Run	.002	.033	.005	.043
Short-Run	0	.006	-.002	.026
Statutory Tax Credit (.1)				
Long-Run	.005	.082	.012	.112
Short-Run	0	.015	-.006	.067

that the R&D rental decreases by $-.153\%$ and $-.395\%$ respectively. Applying these percentages in the same manner as we did to derive Table 9.2, yields Table 9.3. Clearly the effects are uniformly greater than those found in Table 9.2. The elasticities are about twice as large (in absolute value). Thus, for example, under the policy of no reduction in tax deductible R&D expenditures, in the long-run R&D capital increases by $.082\%$ and patent frequency increases by $.112\%$, as the statutory R&D investment tax credit increases by 1% .

When we compare Table 9.3 to the bottom half of Table 9.1, we arrive at the same conclusions for physical capital and labour as we did when Table 9.2 and the top half were related. The major differences occur for R&D capital and patent frequency. From Table 9.3, we can see that even under the effective tax credit rate, which is half the statutory rate, the long-run demand for R&D capital increases by almost twice as much as that caused by the physical investment tax credit, which does not reduce the depreciation base. In the short-run the relative difference is three fold. With respect to patent frequency increases in the physical investment tax credit generate substantially more patents than the other credit. This occurs for both the short and long-runs. However, with the gap closed between the effective and statutory rates, the R&D investment tax credit is significantly more effective in stimulating R&D capital expansion and patents.

An interesting comparison centres around the issue of whether increasing the utilization of the R&D investment tax credit stimulates R&D capital and patents relatively more than a policy of

a tax credit which does not reduce the tax deductible R&D expenditures. This issue can be determined by comparing the bottom half of Table 9.2 to the top half of Table 9.3. Clearly, changing policy such that all the tax credits are utilized (and the credit reduces the tax deductible R&D expenditures) dominates a policy change which does not have the credit reducing the tax deductible R&D expenditures (but the credits are underutilized). The former policy stimulates the demand for R&D capital 33% and patent frequency 40% more than the latter. The most pressing policy change of the two is to curb the underutilization problem.

9.3 R&D Investment Incremental Tax Allowance

The previous tax credits had at least one common aspect. They were based on the R&D expenditure in the current year. The incremental tax allowance is based on the difference between the current R&D expenditures and the three year moving average. If current expenditures exceed the three year moving average, then γ_r of this excess is added to the allowable tax deductions pertaining to R&D investment. For example, with \$1 in current R&D expenditures which also represents the excess over the average of the past three years, there is a tax reduction of $$(1 + \gamma_r)u_c$. The post tax cost of the R&D investment is $$(1 - (1 + \gamma_r)u_c)$. Thus, with a corporate income tax rate of .46, and an incremental R&D investment tax allowance rate of .5, the tax reduction on a \$1 expenditure, which is also the excess over the base, is equal to \$.69.

To determine the impact of a change in the incremental R&D investment tax allowance rate (γ_R) on factor proportions, production and adjustment costs, consider, once again, the rental rate on R&D investment. From $w_R = p_R[(\rho + \delta_R)((1-u_C)(1-v_R)-d_R) + \psi_R(r_b(1-u_C) - \rho)]$, the tax allowance rate affects the rental through d_R . By definition, $d_R = u_C \gamma_R \int_0^\infty e^{-\rho\tau} \mu_R(\tau) d\tau$ (see the discussion on page 53). Under the legislation over the sample, the time period in determining d_R is the current and three previous periods. Thus current period's R&D expenditures enter into the calculation of the present tax allowance, and into the computation of the following three years. This is due to the fact that the base of the allowance rate is the excess of the current expenditures over the average of the previous three years. This means that we can define $\mu_R^n = \sum_{\tau=0}^3 \mu_R(\tau) / (1+\rho)^\tau$, where $\mu_R(0) = 1$, $\mu_R(\tau) = -1/3$ for $\tau = 1, 2, 3$, and so

$w_R = p_R[(\rho + \delta_R)((1-u_C)(1-v) - u_C \gamma_R \mu_R^n) + \psi_R(r_b(1-u_C) - \rho)]$. Now we find that a 1% increase in the tax allowance rate decreases the rental rates by $-[p_R(\rho + \delta_R) u_C \mu_R^n \gamma_R / w_R]\%$. In this case the percentage is .066%. Notice, of all the tax incentives which affect the rental rate on R&D capital, this latter policy generates the most inelastic response. Applying the percentage change in the rental to the second row of Tables 7.2 and 7.4 and the third column of Table 8.2, yields the figures in Table 9.4. We can observe that the effects on the factor demands and inventive output are the most inelastic of all the investment tax incentive policies. It is interesting to notice, though, that the elasticities in Table 9.4 are not substantially different from

Table 9.4
Long and Short-Run R&D Investment Incremental Tax Allowance
Elasticities

	Factor Demand			Patent Frequency
	K_p	K_r	L	
Long-Run	.001	.014	.002	.019
Short-Run	0	.003	-.001	.011

those relating to the R&D investment effective tax credit rate. The similarity of these effects is caused by the underutilization of the credits. The lack of credit utilization causes the rental rate to decrease by only $-.084\%$, even though the credit is based on total R&D expenditures. This percentage is only 27% greater (in absolute value) than the decrease in the rental associated with the allowance, which is based on incremental R&D expenditures. Because the effects on the rental rates are similar, the consequent impact on factor demands and patent frequency are not significantly different.

10. Conclusion

In this study we have analysed the determinants of patent frequency, the demands for R&D and physical capital and labour requirements. There were four objectives of this study. The first was to determine the impact of the investment tax incentives on factor demands and inventive output (or patent frequency). The second purpose . . . to investigate the nature of non-inventive output influences on patent frequency and the structure of production. The last two objectives were to determine the adjustment costs, and the financing composition associated with the accumulation of the physical and R&D capital stocks.

The three tax incentives considered were the physical and R&D investment tax credits, and the R&D investment incremental tax allowance. We analysed these incentives in a number of different ways. First, we considered the effective tax credit and allowance rates. Second we analysed the credits under the circumstances in which they decreased or did not decrease the depreciation base of the relevant capital stock. Third, we investigated the statutory R&D investment tax credit rate. The comparison of the results under the statutory and effective rates allowed us to determine the impact of policies designed to increase the degree of credit utilization.

Increases in the physical investment tax credit generated increases in the short and long-runs for all factor demands and the supply of inventive output. Of the factor demands, the greatest response emanated from physical capital. In addition, patent frequency increased by the same percentage as physical capital and substantially more than the increase in R&D capital.

Labour requirements, not only increased as a result of the higher tax credit rate, but the effect dominated that found for R&D capital.

Turning to the R&D investment tax credit, we found very little effect on the demands for physical capital and labour. This result was sustained for both the short and long-runs. Moreover, because the credits are severely underutilized, the effect on R&D capital was only slightly greater than that obtained from increases in the physical investment tax credit rate, while patent frequency increased by half the percentage under the latter rate. Once the utilization problem is solved, so that statutory rate on the R&D investment tax credit is in effect, the increase in R&D capital is significantly greater than for the physical investment credit. The increase in patent frequency became equalized under the two tax regimes. In our results, we found that closing the gap between the effective and statutory tax credit rates, through for example eliminating the limit on the amount of the tax credit a firm can claim in any one year, dominates the policies of increasing the rate (with the same degree of utilization) and of abolishing the rule of having the credit reduce the tax deductible R&D expenditures.

The last tax incentive considered was the R&D investment incremental tax allowance. The effect of increasing the allowance rate was to generate effects similar (although smaller) to those for the R&D investment effective tax credit rate. In a sense this pointed out the severity of the credit underutilization issue with respect to R&D capital requirements and patent frequency. An allowance based on incremental R&D expenditures elicited almost

the same response as a credit on total expenditures.

Thus the general conclusions were that:

1. The most effective tax incentive (of those considered) to generate increases in factor demands and patent frequency is the physical investment tax credit.
2. The most important policy change directed towards R&D capital formation is to increase the utilization of existing tax credits.
3. The least effective measures to stimulate R&D capital accumulation and patent frequency were both the R&D investment incremental tax allowance and the effective tax credit rate (at the existing degree of utilization).

The second objective of this study was to determine the short and long-run responses of the factor demands and patent frequency to increases in non-inventive output (or inflation adjusted sales). We found that all the effects were positive and those in the long-run exceeded the short-run results. In addition, the short-run effects were less than unity, while the long-run were approximately equal to unity. In the short-run because the capital stocks were subject to adjustment costs, increases in non-inventive output were satisfied relatively more by labour requirements than by the capital inputs. In the long-run after the adjustment costs had been absorbed all inputs increased in the same proportion to each other, and in the same proportion to non-inventive output. Patent frequency behaved in a similar manner to the factors of production. The short-run increase was less than the proportional increase in non-inventive output, while in the long-run both outputs changed in the same proportion. In the

present context we did not find that patent frequency increased proportionately more than firm size (represented by inflation adjusted sales).

The third and fourth objectives related to the financing composition and cost of adjustment of physical and R&D capital accumulation. We estimated that about half of the growth in physical capital is financed by debt, while for R&D capital only a tenth of the expansion is bond financed. We also estimated that there were significant adjustment costs associated with the capital inputs. Indeed it takes about 5.5 years for firms to adjust to their desired stock of R&D capital, while only 3.5 years for physical capital. In addition, along the adjustment process increases in one of the capital stocks speeds up the process for the other. Thus there is a form of complementarity in the adjustment to the desired stocks. Finally, it is worth mentioning that although there are more tax incentives directed towards R&D relative to physical capital, the latter stock adjusts more rapidly to its long-run desired level.

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